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CR 89.005

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Contract Report

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An Investigation Conducted by
ABAM Engineers Inc., Federal Way, WA
Sponsored By Naval Facilities
Engineering Command

AD-A206 496

PRESTRESSED CONCRETE FENDER PILES: FENDER SYSTEM DESIGNS

ABSTRACT Designs for prestressed concrete fender piles for use at Navy piers in a wide range of fendering applications are presented. Two types of fender piles are discussed: an energy absorbing fender pile for use with camels and a reaction fender pile for use with foam-filled fenders.

Complete fender system designs incorporating either timber or steel wales with the baseline energy-absorbing prestressed concrete fender piles, as well as a new class of fender pile to resist the reaction from foam-filled fenders, are presented.

Design aids are given in the form of easy-to-use graphs. Design examples are also presented.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

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METRIC CONVERSION FACTORS

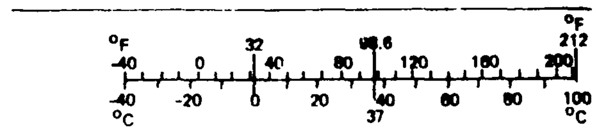
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	*tonnes (1,000 kg)*	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius *temperature*	9/5 (then add 32)	Fahrenheit *temperature*	°F



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Designs for prestressed concrete fender piles for use at Navy piers in a wide range of fendering applications are presented. Two types of fender piles are discussed: an energy absorbing fender pile for use with camels and a reaction fender pile for use with foam-filled fenders.

Complete fender system designs incorporating either timber or

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steel wales with the baseline energy-absorbing prestressed concrete fender piles, as well as a new class of fender pile to resist the reaction from foam-filled fenders, are presented.

Design aids are given in the form of easy-to-use graphs. Design examples are also presented.

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SECTION 1

SUMMARY

The Department of the Navy, through the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme, California, has initiated a program to develop prestressed concrete fender piles for use at Navy piers in a wide range of fendering applications. This report completes the design portion of the multiphase testing, analysis, and design effort [1.1].

Two types of fender piles are discussed in this report: an energy-absorbing fender pile for use with camels and a reaction fender pile for use with foam-filled fenders.

Complete fender system designs incorporating either timber or steel wales with the baseline energy-absorbing prestressed concrete fender piles are presented. The system designs were developed from conceptual studies performed in Phase IV of this study [1.2].

Design of a new class of fender pile to resist the reaction from foam-filled fenders is presented. Design criteria and design aids were developed for a 24-in.-square prestressed precast concrete pile with concrete strengths of 6000, 7000, and 8000 psi. The design aids are in the form of easy-to-use graphs. A design example is also presented.

As a result of this phase, detailed drawings of complete fender systems and design aids for a new class of fender pile are available to assist in procuring precast prestressed concrete fender pile systems for Navy facilities.

SECTION 2

INTRODUCTION

To encourage and promote the use of energy-absorbing precast concrete fender piles it is necessary to develop system details that may be used by engineers to incorporate them into complete designs. The systems presented herein are very similar to those used at existing Navy facilities. The details are also prepared with the thought in mind that these fender piles can be adapted to existing timber or steel fender systems without significant changes to existing chock and wale systems. The fender systems are discussed in Section 3.

The concrete reaction fender piles serve to transfer the reactions from a foam-filled fender into the pier or wharf and harbor bottom. Energy absorption of a foam-filled fender is sufficient in itself. Energy absorption by the concrete piles adds to the system overload capacity. In an effort to minimize costs yet provide the necessary performance and durability requirements established in previous phases and to make more efficient use of the prestressed concrete piles as reaction piles, the design criteria developed in previous phases were reevaluated. The reaction fender piles selected are discussed in Section 4.

SECTION 3

FENDER SYSTEMS DESIGN AND DETAILING

The two fender system designs presented in this report employ the prototype energy-absorbing concrete fender pile that was developed in previous phases of the study. The standard pile is 18 in. square and is prestressed with twenty 1/2-in.-diameter strands in a rectangular pattern. Depending on the site-specific conditions and the required system energy, a different size pile could be used. For more specific information on the pile design itself, refer to Phase III of this study [3.1].

The drawings for the fender pile systems are contained in Appendix A. Two schemes are presented: Alternate 1 uses timber wales and Alternate 2 incorporates a steel W-section wale. The timber wale system will be less expensive initially than the steel wale and long-term maintenance for the timber wale will be less.

The assumptions used in developing the fender system alternates are

- The berthing energy of the ship is absorbed entirely by the concrete fender pile.
- The fender pile is contacted by the ship only at the water line and not at the top of the pile. This requires either a log camel or some other type of floating separator between the ship and the pile. (A partial detail is provided for use when this assumption is not met.)
- The system details are developed for new facility construction but can be easily adapted to existing facilities.

The system elements common to both alternates are listed below:

- Timber chocks
- No rub strip on the pile face
- Pile spacing = 8 ft

Following is a discussion of critical components of the system and their purpose:

The fender system is designed so that the fender piles absorb all the berthing energy; therefore, rubber fenders behind the piles at the deck level are not required. Rubber fenders are needed when the pile acts as a "reaction pile" and transfers the berthing force up to the pile top and into the rubber fender, which in turn absorbs the energy. Rubber fenders would also be required if a camel or separator were not used to berth a ship, and the ship contacted the pile top directly.

In the case where the fender pile absorbs the energy and the rubber fender is omitted, the fender system (i.e., wale and chock) can be supported directly off the pier rather than off the fender piles. The fender pile is then held against the chock and wale with a restraining strap. The advantage of this system is that if some piles are broken, the remaining fender system has not lost its vertical support.

The pile is held against the wale using a steel strap that projects slightly beyond the face of the pile. Should a vessel berth directly against the top of the pile, consideration should be given to protecting the vessel and strap. There also would be no energy absorption possible in the system. This emphasizes the need for a camel or separator. It may be advantageous to project the chock beyond the face of the pile to prevent ship contact with the steel strap, which could damage both the ship paint and strap around the pile.

A method of attaching the wale to the pier is presented in the drawings. A T-bolt insert is cast in the face of the concrete pier. The 1-in.-diameter T-bolt can then be installed and rotated 90 degrees and locked in place. The holes for both the blocking and the wale should be drilled based on the as-built location of the T-bolts. Other options for attaching the wale to the pier include screw anchors, coil bolts, and drill and epoxy bolts in the pier face. Anchor bolts could also be cast in the pile cap or bullrail with the ends projecting out. This may not be as desirable because it requires holes to be drilled in the side of the formwork.

The T-bolt or other connector that supports the wales must be properly tightened. The longitudinal forces that may be imparted to the fender system due to berthing must be resisted by both friction between the wale and blocking, and the blocking and pier. The component of longitudinal force normal to the pier increases the friction resistance of the fender system. The shear capacity of the bolt alone is small due to the fact that the blocking behind the wale may allow bending in the bolt if the friction force is overcome.

The purposes of the blocking between the pier and the wale is to provide a means to adjust for irregularities in the bullrail. This offset also provides access to the bolts that connect the chock and wale together and the wale splices. The blocking could be either solid rubber or timber.

Another possible option is to omit the wale and attach the chock and pile and blocking directly to the pier face with through bolts and screw anchors. This option is less desirable than methods previously described because field drilling of the precast prestressed concrete pile may be required in order to line up with the screw anchors.

If rubber fenders are used between the wale and the pier, the wale is usually designed to distribute the reaction from the pile top into several rubber fenders. When a solid block is used behind the wale in place of the rubber fender, there is no distribution of force. In this case the wale and blocking provide a standoff between the pier and pile. The minimum standoff might be controlled by the ability of the pile driving equipment to drive close to the pier. There might also be a minimum distance required between the outboard support pile of the pier structure and the fender pile. The timber wale is shown as two pieces rather than one large piece but either option may be used. The type of timber wale used will depend on regional timber availability and costs.

The purpose of the chock is to restrain the pile from moving along the pier face and to keep it from twisting in plan. To accomplish this, the timber chocks should be cut for a tight fit. Because of their short length, the chocks are to be one-piece units.

The chock and wale are designed to support personnel walking on the fender system. If it is necessary to support additional live load (cables, steam lines, etc.), the connection of the wale to the pier should be reevaluated.

For the timber wale alternate system design with rubber fenders behind the head of each pile, the fender system is attached directly to the pile. The pile is then held against the pier by a chain that connects to a steel hardware unit cast into the pier. The most positive method of attaching the chock/wale to the pile is to use a through bolt. The detail for the through bolt requires more accurate driving tolerances than the steel strap does. The through bolt also presents more of a fabrication problem because of the number of strands in the pile. In order to resist the longitudinal forces, a set of horizontal chains is required at certain intervals to transfer the force from the wale into the pier.

SECTION 4

REACTION FENDER PILE DESIGN

4.1 INTRODUCTION

Foam-filled fenders are used extensively in the Navy for both absorbing the energy due to ship berthing and as a standoff between the ship and the pier structure when the ship is moored. Currently, there are many different methods of transferring the reaction of the foam-filled fender to the pier structure. In Phase IV of this study [1.2], different concepts were presented using a 24-in.-square prestressed concrete fender pile as a reaction pile behind a 6-ft-diameter by 12-ft-long foam-filled fender. The purpose of this section of the report is to develop design criteria and design aids for the 24-in.-square pile as a continuation of the previous phase.

The foam-filled fender is assumed to absorb all the required energy from ship berthing. The reaction associated with the berthing energy is transmitted through the foam-filled fender either directly into the concrete reaction piles, or into a bearing panel to help distribute the loads to the piles. The actual contact length over which the foam-filled fender will deliver the reaction force must be taken into account.

The pile is designed as a "stiff" member, transferring the reaction from the foam-filled fender into the pier and harbor bottom. The design includes a higher level of prestress force with fewer strands than did the "soft" pile, whose primary purpose was to absorb energy, not to transfer a reaction. The "stiff" design results in a more economical pile to resist a reaction force than the "soft" pile but it does not have the energy absorption capability.

4.2 DESIGN CRITERIA

The horizontal force on the pile due to the foam-filled fender reaction could result from a static or dynamic force. The static force could be from either wind or current. The dynamic force would result from berthing the vessel. Regardless of the origin of the force, it must be factored to obtain an ultimate load (versus a working load) to be used in the reaction pile design.

The energy absorbed by the "stiff" pile is not counted on in the design. For static loads, energy is not a design parameter and for dynamic loads the foam-filled fender is assumed to absorb all the energy. Therefore, energy absorbed by the pile is not critical but adds to the overload capacity.

The "effective" number of concrete piles required to resist the ultimate reaction force is not necessarily the number of piles that must be provided. The word effective is used because the designer must calculate the actual distribution of load to each pile. The "system design" is analogous to a beam on elastic foundation, which may result in some piles being more heavily loaded than others. If a bearing panel is required, the load distribution also changes. The pile loaded with the highest reaction in the system will control the design. See the previous phase of this study for items to be considered [1.2].

4.3 PILE REINFORCING CONFIGURATION

The pile is designed as a vertical flexural member, not a compression column. The "stiff" pile concept developed in the previous phase was chosen over the "soft" pile concept. For details of the design, refer to the previous phase of this study. The design drawing for the 24-in.-square reaction pile is found in Appendix A. A total of twenty-eight 1/2-in. strands are used along with No. 3 confining steel.

SECTION 5

REACTION FENDER PILE DESIGN AIDS

5.1 PURPOSE OF DESIGN AIDS

Design aid figures (Figures 5.1, 5.2, and 5.3) are presented to assist the designer in selecting the number of "effective" piles required to resist the reaction from a foam-filled fender or other marine fendering unit. This report addresses the design problem from the point of knowing the maximum factored force imparted by the fender into the pile.

The issue of what design criteria should be used to design the marine fendering unit is beyond the scope of this report, but must be dealt with in the context of arriving at the factored loads. The derivation of the maximum factored force applied to the pile due to wind, current, and ship berthing is also beyond the scope of this study. The important requirement for designing the concrete reaction piles is that the loads must be factored loads, not working loads.

Some general points to be considered are

- The designer must calculate the factored (or ultimate) loads for both wind plus current and berthing.

- If the maximum factored loads are close to the maximum rated reaction of the marine fendering unit, use the rated reaction for the reaction pile design.

- If a larger fender than required by reaction design is used to provide a standoff between the ship and pier, and the actual factored loads are much smaller than the rated reaction of the fender, use the maximum factored load for the reaction pile design.

- Consideration should be given to the tolerances allowed by Military Specifications [5.1] for the maximum rated reaction when using the rated loads.

5.2 THEORY AND DEVELOPMENT

When using the design figures to select the number of reaction piles required, the design load must be considered as a factored ultimate load and not a service level load. Military Handbook 1025/1 [5.2] gives guidelines for the ultimate load factors to be used. Figures 5.1, 5.2, and 5.3 present plots of the "design strength load capacity" versus the "design span length" of the piles.

The pile load capacity is limited by the moment capacity of the section for a given concrete strength when loaded no closer than 6 ft from the support. This 6-ft dimension is based on the assumption that the top of the pile extends a mirimum of I ft beyond the support. When the pile is loaded closer than 6 ft, the load capacity should be calculated. Load capacity will be limited by either the shear capacity of the section or a reduced moment capacity due to the strand development length available.

The controlling moment capacity in the pile is defined as "the moment at which the extreme fiber concrete compressive strain is equal to 0.0021 in./in. if the maximum strand stress is less than 240 ksi." Piles similar to the reaction piles have been load tested and shown to perform well under cyclic loads producing the above-mentioned strain. In lieu of taking the ultimate capacity of the pile at the design code strain limit of 0.003 in./in. and multiplying it by a strength reduction factor (ϕ), we have chosen the moment at this lower strain as the ultimate factored capacity.

The moment capacity of the pile is constant for a given concrete strength, and does not depend on pile length or load location for loads applied greater than 6 ft from the support. The corresponding reaction is a function of this moment capacity and varies with pile span length and load location. The corresponding pile reaction into the pier can be calculated by statics and is equal to the shear in the upper portion of the pile. This reaction should be used to check the strength of the existing or new wharf to accommodate the fender reaction.

5.3 DESIGN AID FIGURES

The figures developed in this report are intended for pile support lengths varying from 40 to 90 ft. The range of pile load locations ranges from 6 to 25 ft below the top support. Plotted on the charts are nominal load capacity curves for particular load locations versus pile support lengths. The three charts provided are for concrete strengths (f'_c) equal to 8000, 7000, and 6000 psi and are used to calculate the "effective" number of piles.

5.4 DESIGN PROCEDURE

The procedure to select the number of effective piles follows:

Step 1

a) Determine the pile span length, L_e.

b) Determine the maximum and minimum value of "a," which depends on where the reaction from the foam-filled fender or other marine fendering unit will contact the concrete pile due to tidal variations or other factors (i.e., the fender may also be hung from the structure rather than floating).

c) Choose the pile concrete strength, f'_c, and refer to the appropriate figure.

Step 2

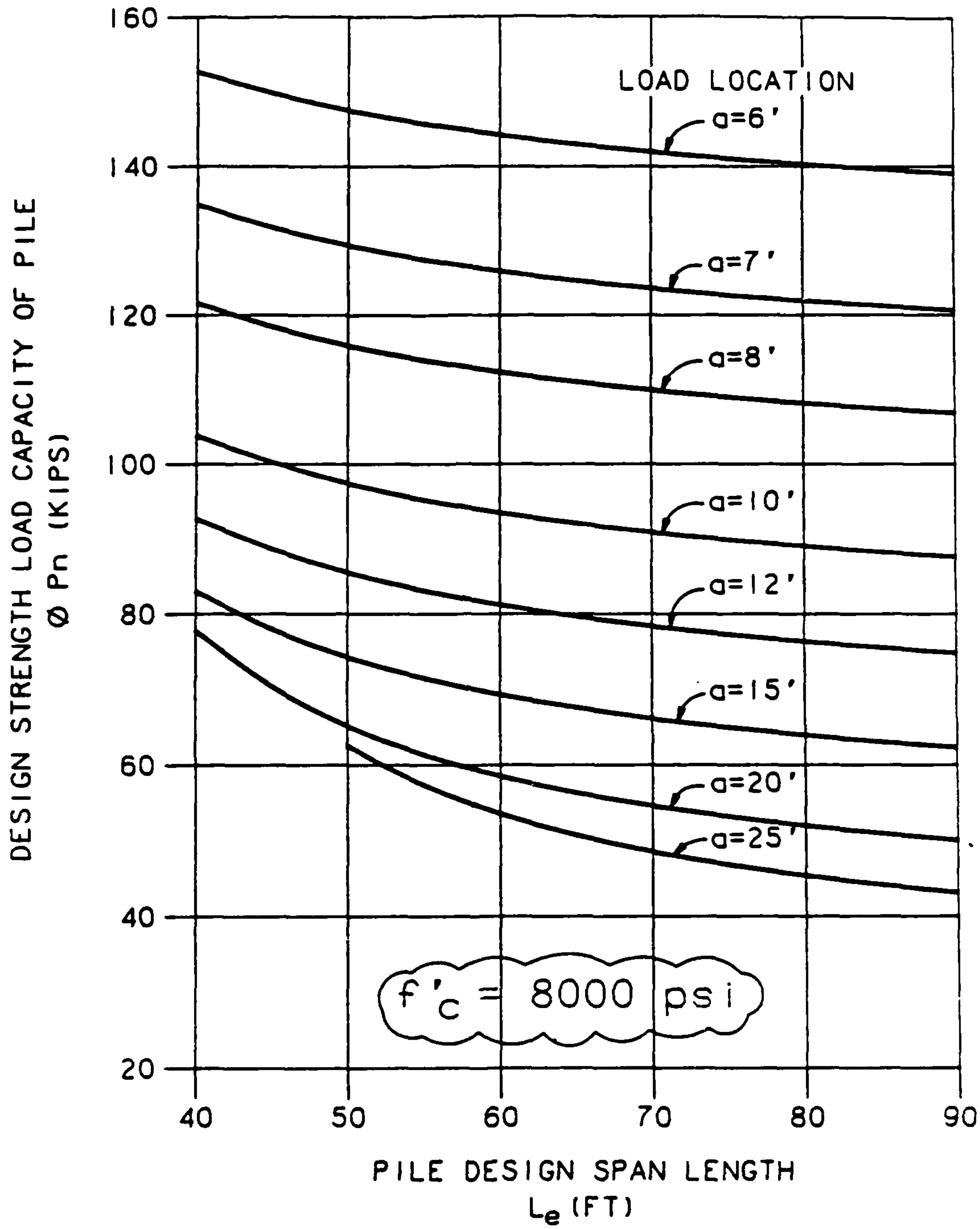
Determine the maximum rated reaction that results when the foam-filled fender is at 60% compression. This criterion may vary for other types of marine fendering. This will be treated as the ultimate load. Check that the factored loads due to wind, current, and berthing are less than the foam-filled fender rated reaction. Refer to Section 5.1 for further explanation.

Step 3

Knowing the pile span length, extend a vertical line up through the two extreme load locations. Follow the intersection of the lines horizontally and read the pile reaction capacity.

Step 4

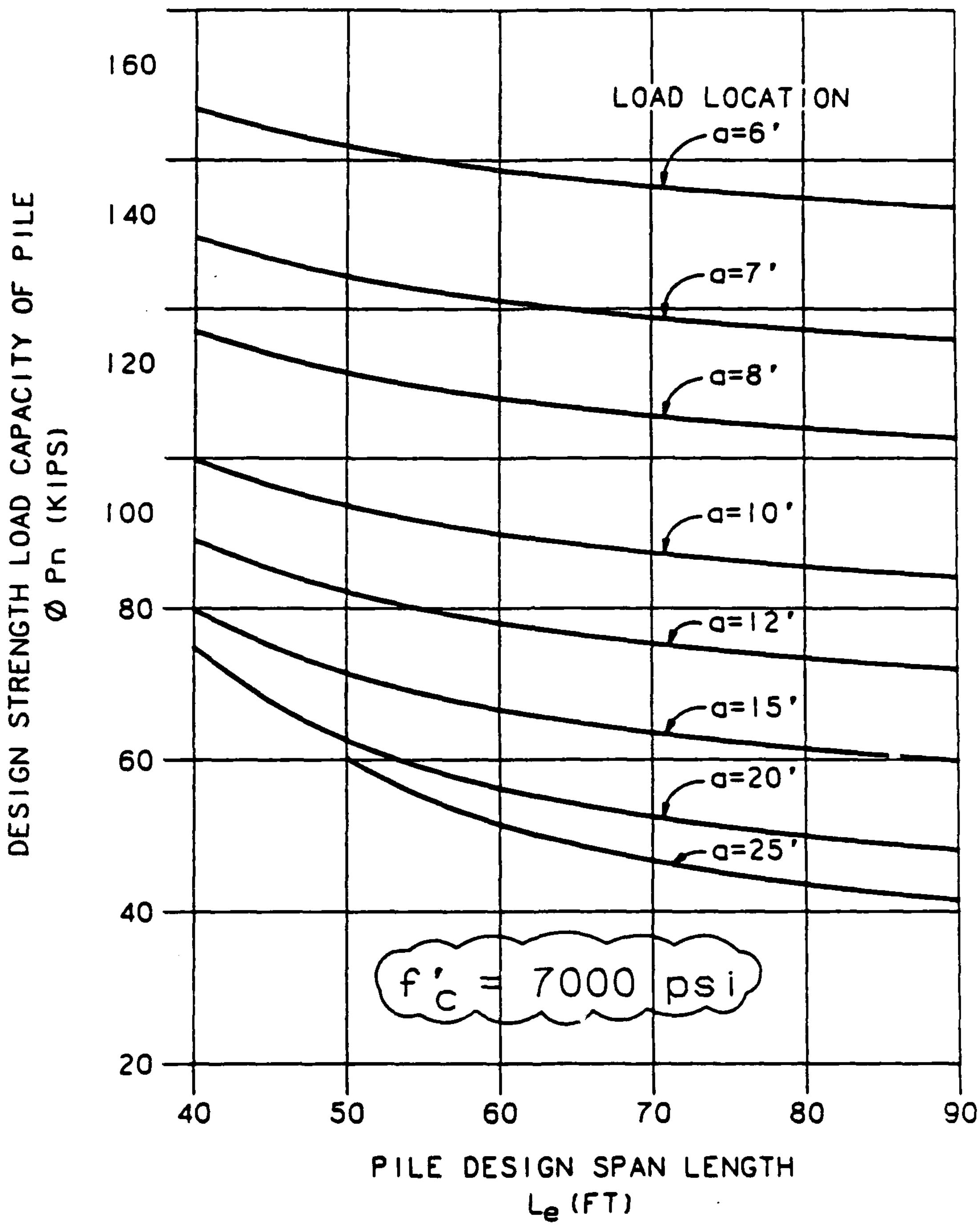
The "effective" number of reaction piles required is equal to the ultimate load divided by the smallest pile capacity found in Step 3.



SCALE: HORIZ	1"=10'-0"
VERT	1"=20 KIPS

NOTE: FOR a < 6'
SEE REPORT

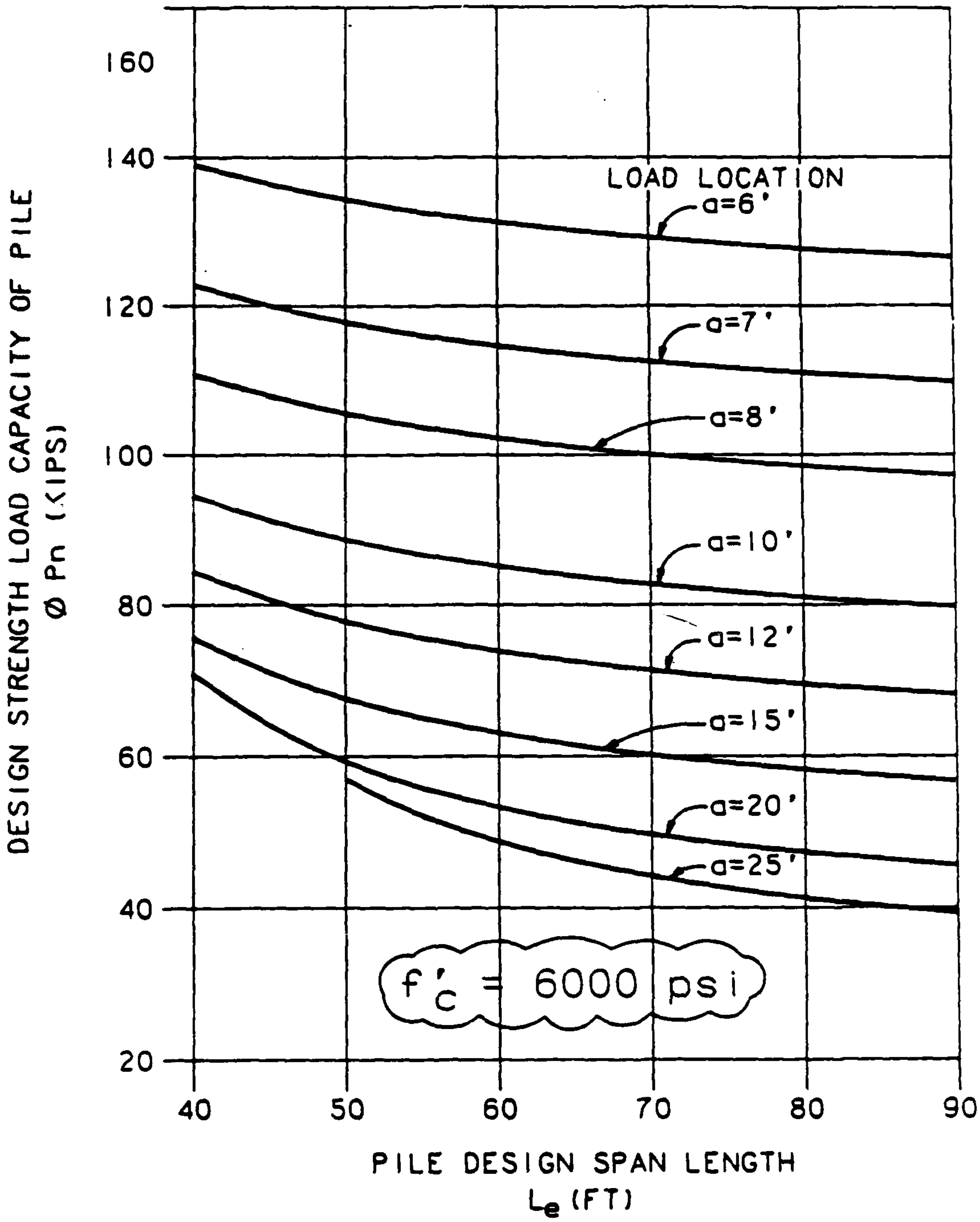
FIGURE 5.1, 24" SQUARE REACTION PILE
WITH f'_c = 8000 psi



SCALE: HORIZ 1"=10'-0"
VERT 1"=20 KIPS

NOTE: FOR a < 6'
SEE REPORT

FIGURE 5.?, 24" SQUARE REACTION PILE
WITH f'_c = 7000 psi



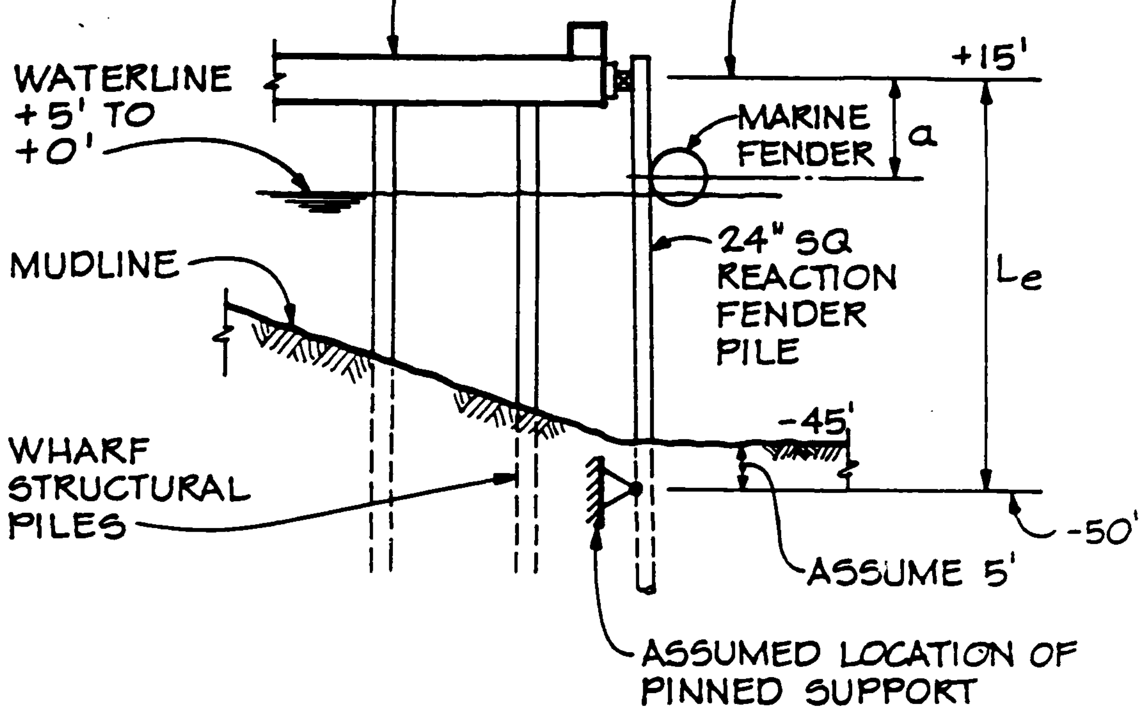
SCALE: HORIZ 1"=10'-0"
VERT 1"=20 KIPS

NOTE: FOR a < 6'
SEE REPORT

FIGURE 5.3, 24" SQUARE REACTION PILE
WITH f'_c = 6000 psi

DESIGN EXAMPLE

STEP 1



a) $L_e = 15' + (+50') = \boxed{65'}$

b) a VARIES, RANGES FROM:
MINIMUM $a = 15' - 5' = \boxed{10'}$
MAXIMUM $a = 15' - 0' = \boxed{15'}$

c) SPECIFY THE 28 DAY STRENGTH OF THE CONCRETE PILE AS f'_c = 8000 psi. THEREFORE USE

DESIGN AID $\boxed{\text{FIGURE 5.1}}$

STEP 2 CALCULATE THE MAXIMUM FACTORED FORCE ON THE REACTION FENDER PILE FROM THE FOAM FILLED FENDER.

⇨ GIVEN: $\boxed{P_u = 200 \text{ Kips}}$

STEP 3 DETERMINE THE NOMINAL PILE LOAD CAPACITY USING FIGURE 5.1.

a) EXTEND A LINE UP VERTICALLY FROM THE KNOWN SPAN LENGTH,

⇨ $\boxed{L_e = 65 \text{ FEET}}$

b) FIND THE INTERSECTION WITH THE LARGER "a" VALUE DETERMINED IN STEP 1.b,

⇨ $\boxed{a = 15 \text{ FEET}}$

c) EXTEND THE LINE OVER HORIZONTALLY AND READ THE NOMINAL PILE LOAD CAPACITY,

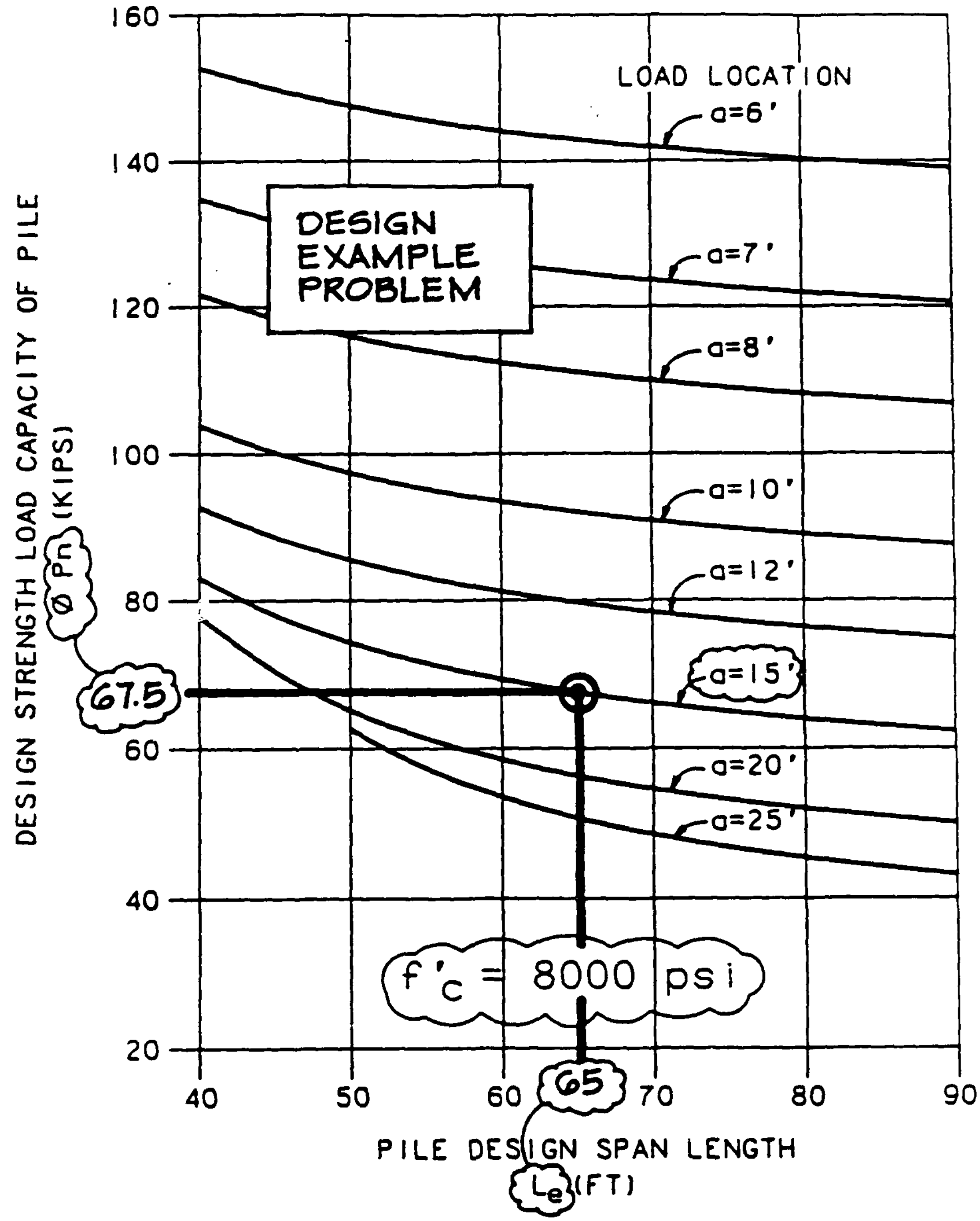
⇨ $\boxed{\phi P_n = 67.5 \text{ Kips}}$

STEP 4 CALCULATE THE NUMBER OF "EFFECTIVE" PILES REQUIRED. SEE SECTION 5 OF REPORT FOR DEFINITION.

$$\text{NUMBER OF "EFFECTIVE PILES"} = N = \boxed{\frac{P_u}{\phi P_n}}$$

$$\Rightarrow \; = \frac{200}{67.5} = 2.96, \text{ SAY } \boxed{N = 3 \text{ PILES}}$$

CAUTION: CALCULATE REACTION AT TOP OF PILE AND CHECK AGAINST STRENGTH OF PIER OR WHARF.



SCALE: HORIZ 1"=10'-0"
VERT 1"=20 KIPS

NOTE: FOR a < 6'
SEE REPORT

FIGURE 5.1, 24" SQUARE REACTION PILE
WITH f'_c = 8000 psi

REFERENCES

1.1 Naval Facilities Engineering Command. Test and Evaluation Master Plan: Development of Prestressed Concrete Fender Piles, Program Element 63725N, Project No. Y0995-SL. Alexandria, VA, June 1984.

1.2 Naval Civil Engineering Laboratory. Contract Report. Prestressed Concrete Fender Piles: Fender System Designs. ABAM Engineers Inc., Federal Way, WA, February 1988.

3.1 Naval Civil Engineering Laboratory. Contract Report CR 88.003: Prestressed Concrete Fender Piles - Final Designs (NCEL Contract No. N62474-86-C-7268). ABAM Engineers Inc., Federal Way, WA, December 1987.

5.1 Military Specification. Fenders, Marine, Foam Filled, Netless. MIL-F-29248(YD), 21 November 1986.

5.2 Military Handbook. Piers and Wharves. MIL HDBK-1025/1, 30 October 1987.

NOTATIONS

a	Distance from support at pile top to location of load application
f'_c	Specified compressive strength of concrete
L_e	Pile design span length calculated from centerlines of supports
N	Effective number of piles
P_n	Nominal load capacity of pile
P_u	Factored (ultimate) force applied to pile from reaction of marine fendering unit
ϕ	Strength reduction factor
$\phi\ P_n$	Design strength load capacity of pile

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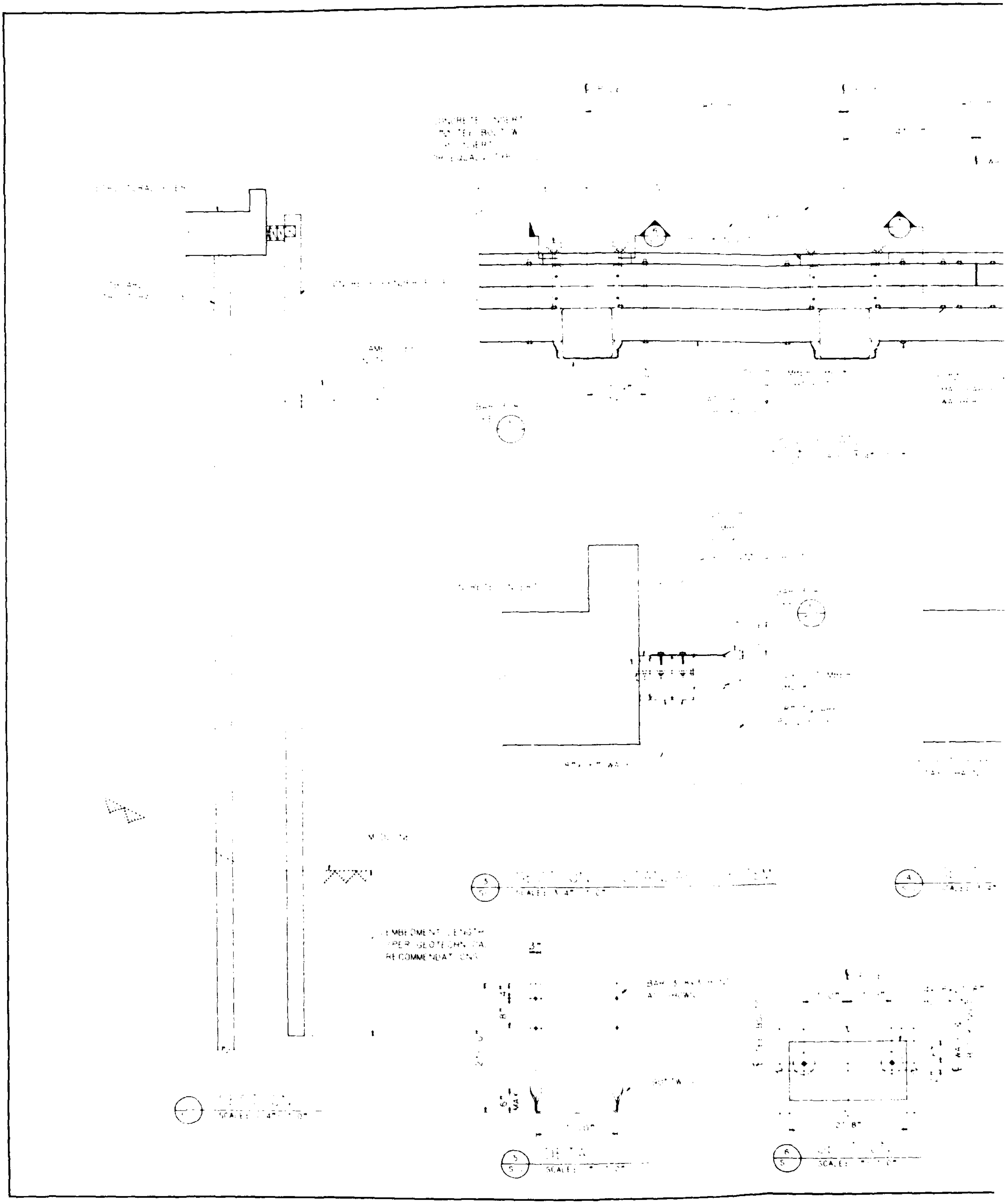
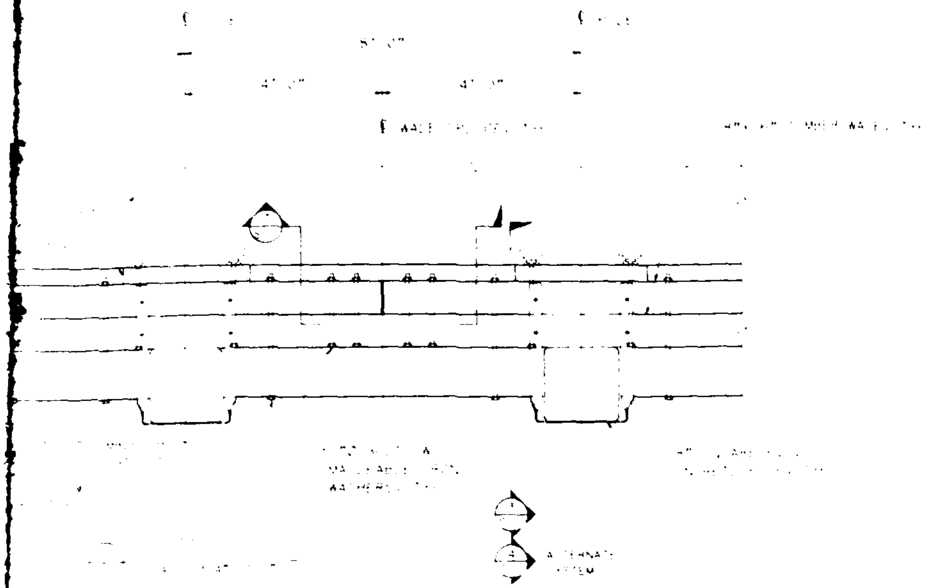
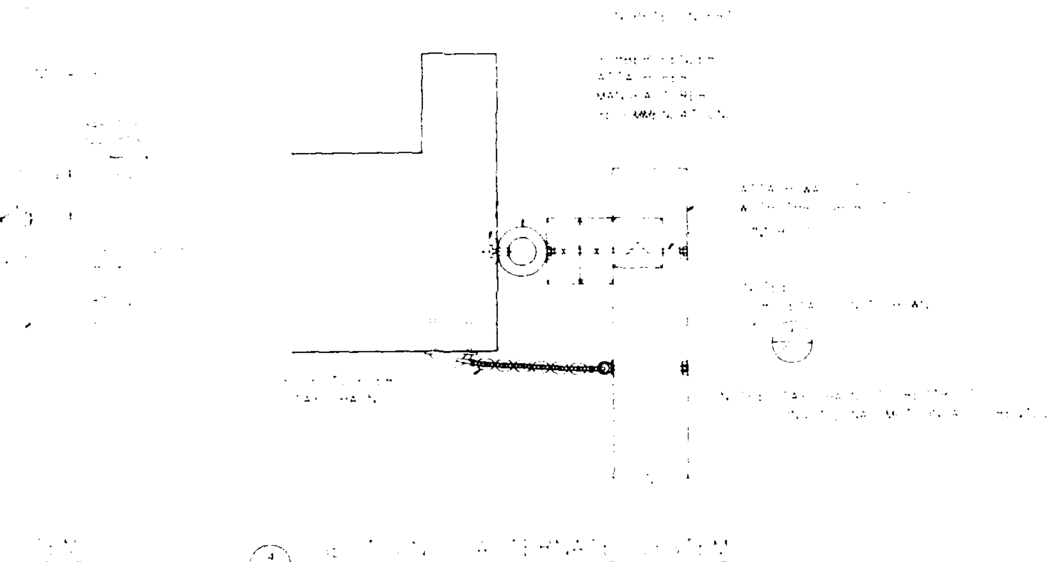
APPENDIX A
DRAWINGS


EMBEDMENT LENGTH
PER GEOTECHNICAL
RECOMMENDATIONS
3"
8"
6" MAX
2'-8"

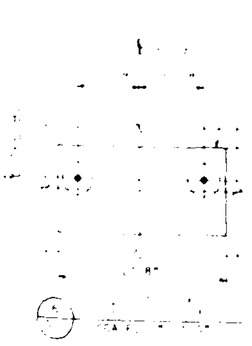


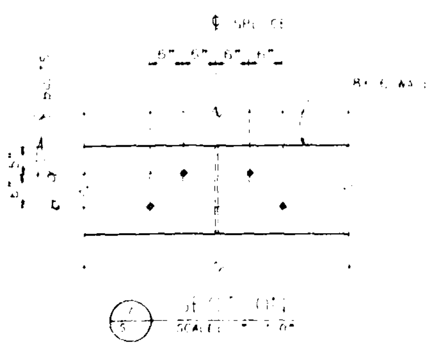
NOTES:

MATERIAL

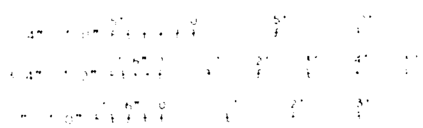


SCALE: 3/4" = 1'-0"





SCALE

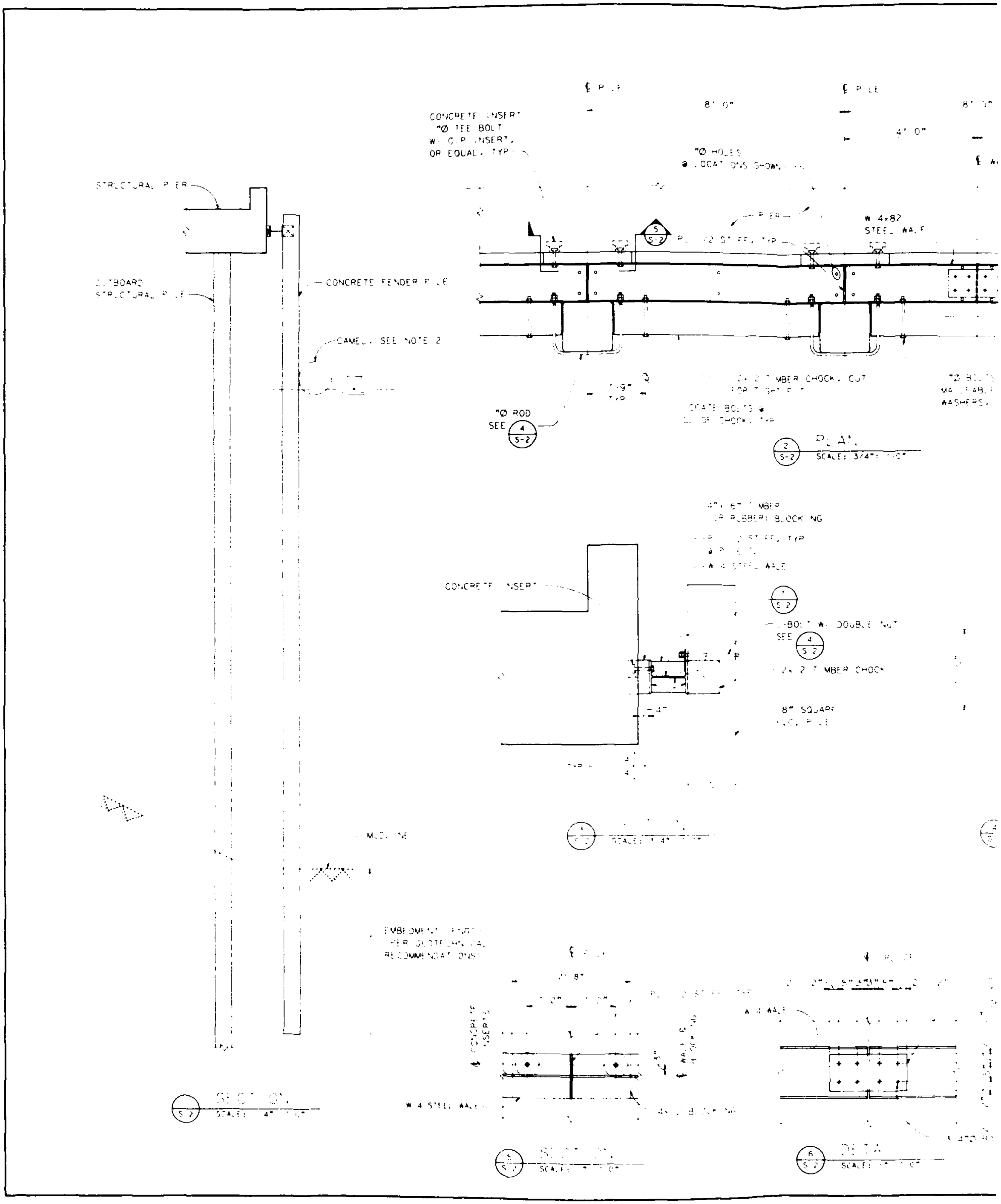


HAS BEEN REDUCED. USE GRAPHIC SCALE.

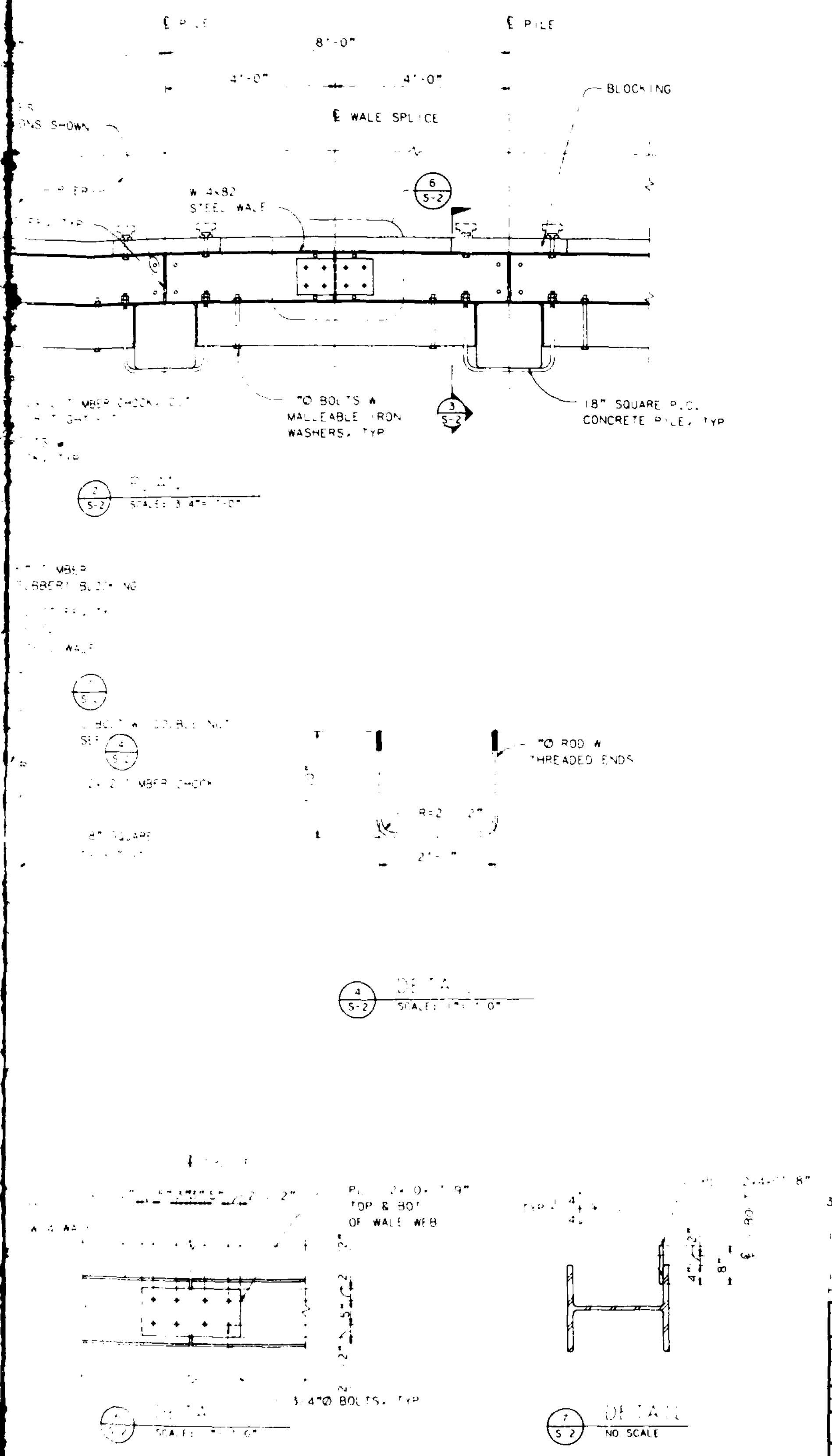
DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND

PRESTRESSED CONCRETE FENDER SYSTEM W/ TIMBER WALE

SCALE: AS NOTED



STRUCTURAL PIER
OUTBOARD STRUCTURAL PILE
CONCRETE FENDER PILE
CAMEL, SEE NOTE 2
MUDLINE
EMBEDMENT LENGTH (PER GEOTECHNICAL RECOMMENDATIONS)
SECTION
SCALE: 1/4" = 1'-0"
CONCRETE INSERT
"Ø TEE BOLT
W/ C.I.P. INSERT,
OR EQUAL, TYP.
℄ PILE
8'-0"
4'-0"
"Ø HOLES
@ LOCATIONS SHOWN
PIER
W 4x82
STEEL WALE
"Ø ROD
SEE 4/S-2
2x 2 TIMBER CHOCK, CUT FOR TIGHT FIT
LOCATE BOLTS @ CL OF CHOCK, TYP.
PLAN
2/S-2
SCALE: 3/4" = 1'-0"
CONCRETE INSERT
U-BOLT W/ DOUBLE NUT
SEE 4/S-2
2x 2 TIMBER CHOCK
8" SQUARE F.C. PILE
W 4 STEEL WALE
SECTION
5/S-2
DETAIL
6/S-2



NOTES

1. FENDER SYSTEM IS DESIGNED FOR NEW CONSTRUCTION. ANCHOR BOLTS MAY BE USED IN PLACE OF TEE-BOLTS.

2. THE PRESTRESSED CONCRETE FENDER PILE IS INTENDED TO ABSORB ALL THE BERTHING ENERGY OF THE SHIP. ALL HORIZONTAL FORCES FROM THE SHIP SHOULD BE TRANSFERRED TO THE PILE AT THE WATERLINE WITH THE USE OF A CAMEL SYSTEM.

3. MATERIALS
   A. BOLTS - ASTM A307, HOT-DIP GALVANIZED IN ACCORDANCE WITH ASTM A 53
   B. STEEL - ASTM A-36, HOT-DIP GALVANIZED HARDWARE IN ACCORDANCE WITH ASTM A 153 AND SHAPES IN ACCORDANCE WITH ASTM A 123.
   C. TIMBER - PACIFIC COAST DOUGLAS FIR, PRESERVATIVE TREAT TIMBERS USING WATER-BORNE SALTS IN ACCORDANCE WITH SPECIFICATION SECTION 0289
   D. ALTERNATE STEEL PROTECTIVE COATING: COAT ALL STEEL SHAPES AND HARDWARE WITH COAL TAR EPOXY. APPLY 3.0 MIL MDFT PRIMER COMPATIBLE WITH TOP COAT AND 8.0 MIL TOP COAT OF COAL TAR EPOXY. IF PROTECTIVE COATING HAS BEEN DAMAGED, REMOVE PAINT SYSTEM IN DAMAGED OR HEAT AFFECTED AREAS BY POWER-WIRE BRUSHING, OR OTHER APPROVED METHODS. IMMEDIATELY APPLY A 1/8 INCH MDFT COAT OF NON-DRYING COAL TAR BASED MASTIC CONFORMING TO FED. SPEC. SS-C-153, TYPE 2.

IF SHEET IS LESS THAN 28"X40", SHEET HAS BEEN REDUCED. USE GRAPHIC SCALE.

NCEL 88-8 2F

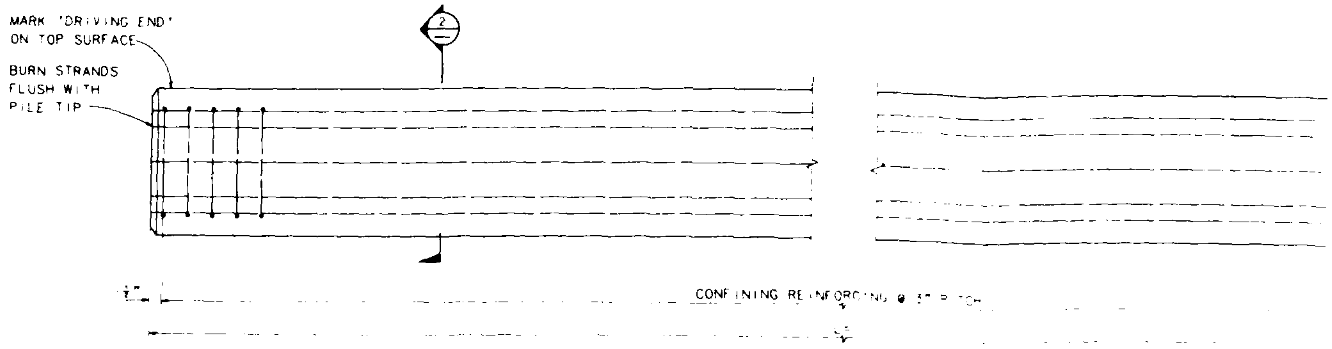
DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND

PRESTRESSED CONCRETE FENDER PILE SYSTEM W/ STEEL WALE

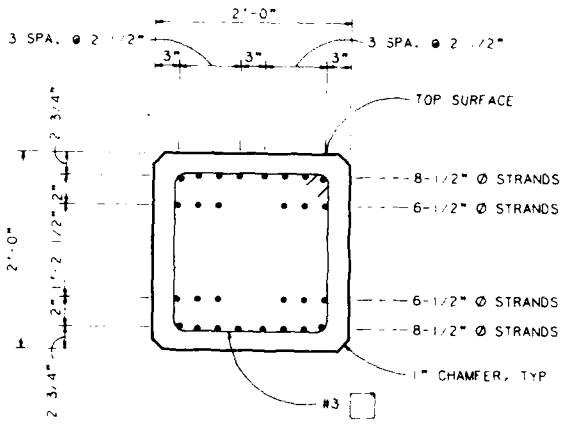
SECTIONS & DETAILS

SIZE F — 80091

SCALE: AS NOTED



24" PRESTRESSED CONCRETE PILE
NTS

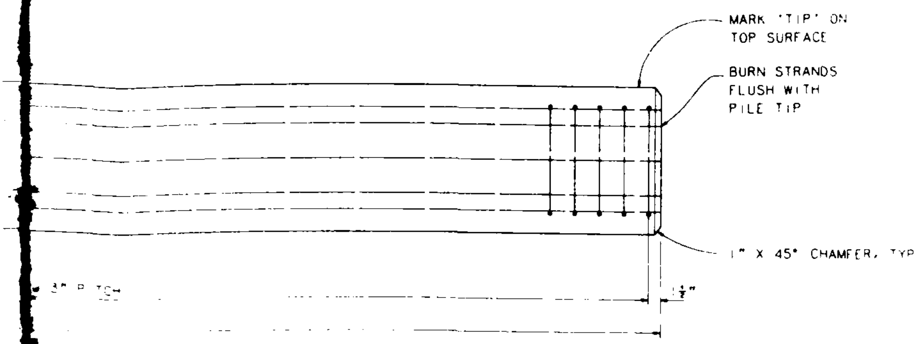


NOTE: DIMENSIONS ARE SHOWN TO CENTERLINE OF STRAND, MAINTAIN 2" MIN CONCRETE COVER TO ALL STEEL.

PILE SECTION
1 1/2"=1'-0"

STRES
PILE SIZE
CONCRETE AREA
TENSIONING UN
INITIAL PREST
DESIGN PRESTR
DESIGN CONCRE

REVISIONS



CONCRETE PILE

NOTES:

1. THIS PRESTRESSED CONCRETE PILE IS DESIGNED AS A REACTION PILE VERSUS A FENDER PILE. A REACTION PILE TRANSFERS FORCES WHEREAS A FENDER PILE ABSORBS ENERGY.
2. LIFTING DEVICE LOCATIONS ARE TO BE DETERMINED BY THE FABRICATOR CONSIDERING HANDLING STRESSES AND DRIVING REQUIREMENTS.
3. PRECAST CONCRETE PILES f'c = PSI AT 28 DAYS
4. CONCRETE STRENGTH AT PRESTRESS TRANSFER, 3500 PSI MINIMUM.
5. REINFORCEMENT
   A. REBAR: ASTM A615, GR 60
   B. PRESTRESSING STEEL: 1/2" Ø, 270 KSI SEVEN WIRE, UNCOATED, STRESS RELIEVED OR LOW RELAXATION STRANDS PER ASTM A416.
6. MARK EACH END OF PILE AS SHOWN.
7. SEE SPECIFICATIONS FOR ADDITIONAL PILE FABRICATION REQUIREMENTS.

STRESSING DATA	
PILE SIZE	24" x 24"
CONCRETE AREA	576 IN^2
TENSIONING UNITS	28 STRANDS
INITIAL PRESTRESS FORCE	810 KIPS
DESIGN PRESTRESS FORCE	660 KIPS
DESIGN CONCRETE STRESS	1145 PSI

IF SHEET IS LESS THAN 28"X40", SHEET HAS BEEN REDUCED. USE GRAPHIC SCALE.

1/2" = 1'-0"

NCEL 88-8-3F

DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND

PRESTRESSED CONCRETE REACTION PILE

24" SQUARE PILE

SIZE F — CODE IDENT NO 80091

SCALE: AS NOTED

APPENDIX B
CALCULATIONS

Project NCEL Phase V	Sheet ____ of ____
	Job No.
	Designer
Subject	Date 5/31/89

ABAM
CONSULTING ENGINEERS

TABLE OF CONTENTS

ENG-002/2-84

Project	NCEL Phase II
Subject	Pile Reinforcing
Sheet	1 of 34
Job No.	
Designer	CWS
Date	6/6/93

ABAM
CONSULTING ENGINEERS

Size $24 \times 24 = 576 \text{ in}^2$

Prestress level $\pm$ 1150 psi

Find number of strands & stress, f_{se}

$$\text{Force} = \frac{1150 \text{ psi}}{1000} \times 576 \text{ in}^2 = \underline{662} \text{ kips}$$

$$f_{se} = \frac{P}{A} = \frac{662 \text{ k}}{N \times .153}$$

N	f_{se} (ksi)	
20	216	Too high
24	180	
28	155	← Ideal, use !
32	135	Too low
36	120	
40	108	

-001/2-84

Check Concrete Tension

Per DM 25.1, sec. 5.4.4.3 c)
Allowable stresses for concrete

Must satisfy one of two criteria:

1) Tension stress $\leq 12\sqrt{f'_c}$

$$P/A = 1.145 \text{ ksi}$$

$$M/S = \frac{778.4^{\text{ft-k}} \times 12''/'}{24(24)^2/6} = 4.05 \text{ ksi}$$

$$12\sqrt{f'_c} = 12\sqrt{8000}/1000 = 1.07 \text{ ksi}$$

$$P/A - M/S = 1.145 - 4.05 = \underline{2.91 > 1.07} \quad \underline{\text{NG!}}$$

2) If concrete member is designed specifically for energy absorption do not have to conform to the above requirements.

Since this pile has been tested to preform in bending, it does not have to conform to the above tension requirement. Pile is okay

---

2-3-34

Used

PROJECT: NCEL FENDER SYSTEM STUDY W/ 24" PILES
DATE: 12/1/87
DESIGNER: CWS
PROGRAM: 'FENDER' DEVELOPED BY ABAM ENGR. INC.

DATA FILE: ~~B:24PILE2~~
PILE NUMBER: 24" SQ. W/ RECTANGULAR STRAND PATTERN
REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

PILE DIMENSIONS:
LENGTH = 65 ft
LOAD FROM TOP = 15 ft
DEPTH = 24 in
WIDTH = 24 in

Stiff

CONCRETE DATA:
STRENGTH f'c = 8 ksi
MODULUS E = ~~4577~~ ksi
PRESTRESS fpc = 1145 psi

STRAND DATA:
STRAND TYPE = LOW RELAXATION
STRANDS = 28
STRESS fpu = ~~270~~ ksi
STRESS fse = 154 ksi
MODULUS E = 28000 ksi

AREA = 1.224 sq.in	DEPTH = 2.75 in
AREA = .918 sq.in	DEPTH = 4.75 in
AREA = 0 sq.in	DEPTH = 6.75 in
AREA = 0 sq.in	DEPTH = 17.25 in
AREA = .918 sq.in	DEPTH = 19.25 in
AREA = 1.224 sq.in	DEPTH = 21.25 in

MOMENT Mn (k-ft)	CURVATURE (rad/in)	CONC STRAIN (in/in)	UPPER STRAND STRESS (ksi)	LOWER STRAND STRESS (ksi)	NA DEPTH (in)
234.8	2.085E-05	0.00050	-148.6	-159.4	24.00
374.4	4.053E-05	0.00070	-144.5	-165.5	17.27
466.3	6.578E-05	0.00090	-140.9	-174.9	13.68
541.3	9.559E-05	0.00110	-137.6	-187.1	11.51
610.3	1.290E-04	0.00130	-134.5	-201.4	10.08
676.5	1.654E-04	0.00150	-131.7	-216.9	9.07
725.5	2.032E-04	0.00170	-129.1	-227.9	8.36
756.8	2.415E-04	0.00190	-126.4	-235.2	7.87
778.4	2.803E-04	0.00210	-123.8	-240.4	7.49
794.2	3.194E-04	0.00230	-121.2	-244.3	7.20
806.2	3.588E-04	0.00250	-118.6	-247.4	6.97
815.7	3.986E-04	0.00270	-116.1	-249.8	6.77
823.4	4.387E-04	0.00290	-113.6	-251.7	6.61
826.8	4.589E-04	0.00300	-112.3	-252.6	6.54

DATA FILE: B:24PILE2
PILE NUMBER: 24" SQ. W/ RECTANGULAR STRAND PATTERN
REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

MOMENT Mn (k-ft)	CONC STRAIN (in/in)	ENERGY (k-ft)	LOAD (kips)	DEFLECTION (in)
234.8	0.00050	0.6	20.3	0.8
374.4	0.00070	2.0	32.5	1.4
466.3	0.00090	3.7	40.4	1.9
541.3	0.00110	6.1	46.9	2.6
610.3	0.00130	9.2	52.9	3.3
676.5	0.00150	13.3	58.6	4.2
725.5	0.00170	17.1	62.9	5.0
756.8	0.00190	20.2	65.6	5.5
778.4	0.00210	22.8	67.5	6.0
794.2	0.00230	25.1	68.8	6.4
806.2	0.00250	27.2	69.9	6.8
815.7	0.00270	29.0	70.7	7.1
823.4	0.00290	30.7	71.4	7.4
826.8	0.00300	31.5	71.7	7.5

PROJECT: NCEL FENDER SYSTEM STUDY W/ 24" PILES

DATE: 11/11/87

DESIGNER: CWS

PROGRAM: 'FENDEP' DEVELOPED BY ABAM ENGR. INC.

Used

DATA FILE: B:24PILE.DAT

PILE NUMBER: 24" SQ. W/ RECTANGULAR STRAND PATTERN

REVISION #: 0

REMARKS: 36 STRANDS W/ 10/8/0 PAT. 1/2" φ

PILE DIMENSIONS:

LENGTH = 65 ft
LOAD FROM TOP = 15 ft
DEPTH = 24 in
WIDTH = 24 in

$\boxed{\text{Soft}}$

CONCRETE DATA:

STRENGTH f'c = 8 ksi
MODULUS E = 4577 ksi
PRESTRESS fpc = 599 psi

STRAND DATA:

STRAND TYPE = LOW RELAXATION
STRANDS = 36
STRESS fpu = 270 ksi
STRESS fse = 62.745 ksi
MODULUS E = 28000 ksi

AREA = 1.53 sq.in	DEPTH = 2.75 in
AREA = 1.224 sq.in	DEPTH = 4.75 in
AREA = 0 sq.in	DEPTH = 6.75 in
AREA = 0 sq.in	DEPTH = 17.25 in
AREA = 1.224 sq.in	DEPTH = 19.25 in
AREA = 1.53 sq.in	DEPTH = 21.25 in

MOMENT Mn (k-ft)	CURVATURE (rad/in)	CONC STRAIN (in/in)	UPPER STRAND STRESS (ksi)	LOWER STRAND STRESS (ksi)	NA DEPTH (in)
125.2	1.092E-05	0.00026	-59.9	-65.6	24.00
157.2	1.429E-05	0.00030	-59.1	-66.5	21.00
263.6	3.821E-05	0.00050	-55.4	-75.2	13.09
342.1	6.961E-05	0.00070	-52.2	-88.2	10.06
418.0	1.054E-04	0.00090	-49.3	-103.9	8.54
495.0	1.438E-04	0.00110	-46.7	-121.2	7.65
573.4	1.837E-04	0.00130	-44.2	-139.3	7.08
652.8	2.246E-04	0.00150	-41.7	-158.1	6.65
725.0	2.639E-04	0.00170	-39.1	-175.8	6.44
787.7	3.004E-04	0.00190	-36.3	-192.0	6.32
843.7	3.348E-04	0.00210	-33.4	-206.8	6.27
893.3	3.681E-04	0.00230	-30.4	-219.7	6.25
933.6	4.020E-04	0.00250	-27.4	-228.5	6.22
965.0	4.373E-04	0.00270	-24.5	-235.0	6.17
988.7	4.743E-04	0.00290	-21.7	-240.0	6.11
998.3	4.933E-04	0.00300	-20.4	-242.1	6.08

DATA FILE: B:24PILE.DAT
PILE NUMBER: 24" SQ. W/ RECTANGULAR STRAND PATTERN
REVISION #: 0
REMARKS: 36 STRANDS W/ 10/8/0 PAT. 1/2" ϕ

MOMENT Mn (k-ft)	CONC STRAIN (in/in)	ENERGY (k-ft)	LOAD (kips)	DEFLECTION (in)
125.2	0.00026	0.2	10.8	0.4
157.2	0.00030	0.3	13.6	0.5
263.6	0.00050	1.3	22.8	1.2
342.1	0.00070	3.0	29.6	1.9
418.0	0.00090	5.6	36.2	2.9
495.0	0.00110	9.4	42.9	4.0
573.4	0.00130	14.2	49.7	5.3
652.8	0.00150	20.1	56.6	6.6
725.0	0.00170	26.4	62.8	7.9
787.7	0.00190	32.7	68.2	9.0
843.7	0.00210	38.9	73.1	10.1
893.3	0.00230	45.0	77.4	11.1
933.6	0.00250	50.4	80.9	11.9
965.0	0.00270	55.2	83.6	12.6
988.7	0.00290	59.3	85.7	13.2
998.3	0.00300	61.1	86.5	13.4

$\frac{2}{3} \times 61.1 = 40.7 > 38.9$

		Sheet	2 of 34
	Project: NCEL Phase II	Job No.	
		Designer	CWS
ABAM CONSULTING ENGINEERS	Subject: Design Criteria	Date	6/14/88

Criteria for Pile Design / Use of Table

Basic design criteria assumptions:

1) These piles are used to resist the reaction from foam-filled fenders.

2) The types of forces resisted are
   a) Wind & current forces
   b) Reaction associated with energy absorption of foam filled fender due to berthing

3) Use Navy Design Manual DM25.1 for design criteria.

   a) Load Factors Sec. 3.4 — 1.25 Wind & Current – U5; 1.7 Berthing – U2

   b) The fender system must be able to absorb 50% more energy than calculated in the DM for a accidental case. The fender system must provide this capacity.

4) The pile design aids are based on the nominal strength of the pile; therefore, they are to be checked with ultimate loads and not working loads.

5) Foam filled fender for design is 6'Ø × 12'-0"
   $P_{u\,(min)} = 186^k$

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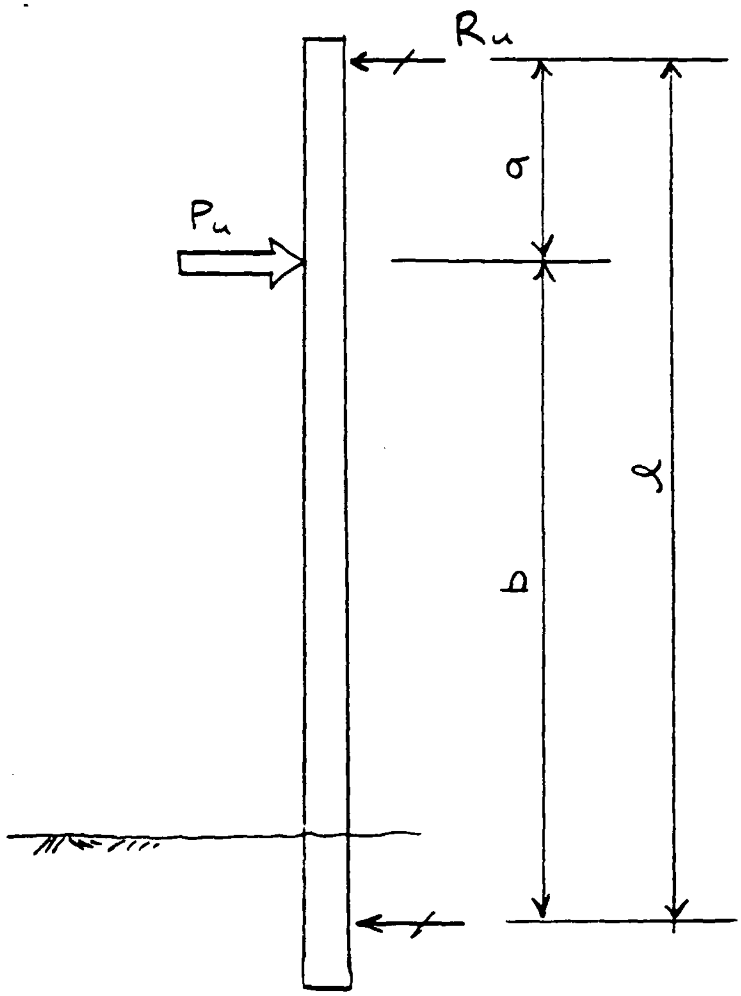
ABAM CONSULTING ENGINEERS	Project NCEL Phase V	Sheet 3	of 34
		Job No.	
		Designer	CWJ
	Subject Design Criteria	Date	6/15/83



ENG-001/2-84

Sheet 7 of 14

Project NCEL Phase II

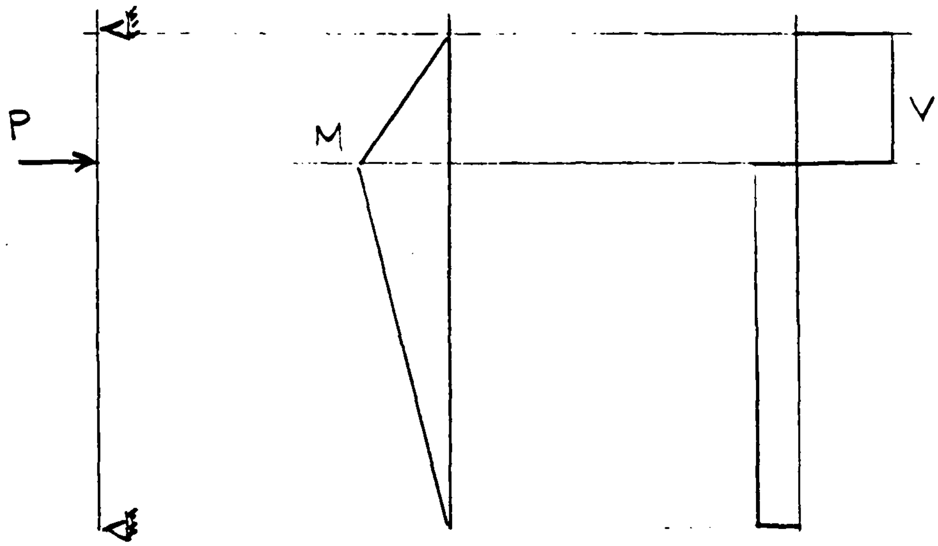
Job No.

Designer CWJ

ABAM
CONSULTING ENGINEERS

Subject Design Criteria

Date 6/15/93



Moment
(k-ft)

Shear
(k)

G-001/2-84

Sheet 10 of 34

Project NCEL Phase II

Job No.

Designer RWS

Subject SHEAR CAPACITY

Date 6/4/82

ABAM
CONSULTING ENGINEERS

Shear

ACI Eqn(11-3)

$V_c = 2\sqrt{f'_c}\,bd = 82.4^k$

$V_s = 84.5^k$

$\phi V_n = .85(82.4 + 84.5) = 141.9^k$

$R = \frac{M}{a} \Rightarrow a = \frac{M}{R}$

For $\phi M_n = 778.4$
$\phi R_n = 141.9$

Max $a = \frac{778.4}{141.9} = \underline{5.5'}$

For $a = 5'$, $R = 155.7^k$

Re-rate by $\frac{141.9}{155.7} = 0.91$

For a=5'	l	$\phi P_n \times .91$ =	$.91\,\phi P_n$ (a=5')	ϕP_n (For a=6')
	40	177.9	162	152
	50	173.1	158	147
	60	169.8	155	144
	70	167.7	153	142
	80	166.1	151	140
	90	164.8	150	139

∴ For $a=5'$, use $a=6'$ values.

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Sheet ___ of 34

Project NCEL Phase II

Job No.

Designer CWS

ABAM CONSULTING ENGINEERS

Subject SHEAR CAPACITY

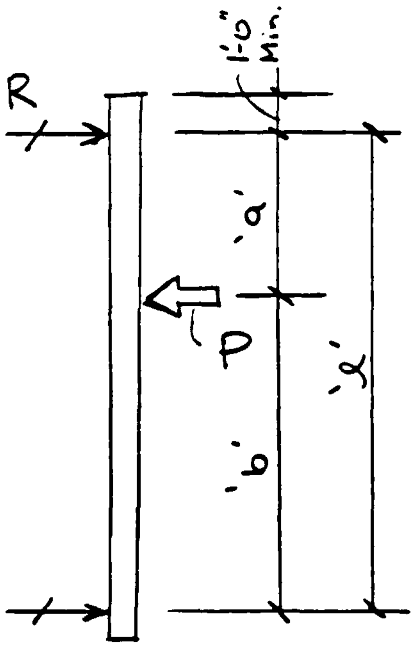
Date 6/14/89

Shear Capacity of Pile

Summary of Shear $\phi V_n = \phi(V_c + V_s)$

f'_c	V_c	V_s	ϕV_n
8	82.4	84.5	141.9
7	77.1	84.5	137.4
6	71.4	84.5	132.5

Note: There is no reduction in shear strength due to strand development along the pile.



As 'a' gets smaller, the reaction R (hence, shear V_u) gets larger also. The controlling 'a' distance is different for each f'_c.

(see next page)

301/2-84

Project NCEL Phase I
Job No.
Designer CWS
Subject SHEAR CAPACITY
Date 6/3/89

ABAM
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Shear Capacity of Section

Per ACI 318-83, Ch. 11, Sec 11.4.2

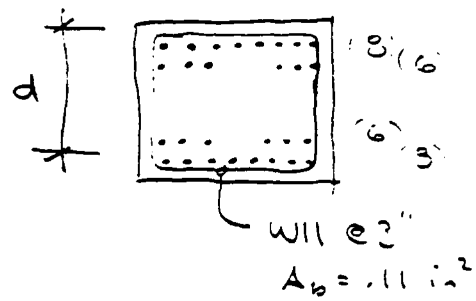
$\phi V_n = \phi (V_c + V_s)$

$\phi = .85$

V_s = shear strength provided by the spiral

V_c = shear strength of concrete

V_s $\qquad V_s = \dfrac{A_v f_y d}{s}$



$f_y = 60$ ksi

$d = 24/2 = 12"$

but $d \geq .8h = .8(24) = 19.2"$ ← Controls

$A_v = 2 \times .11 = .22 \text{ in}^2$ $\qquad s = 3"$

$\therefore V_s = \dfrac{(.22)(60)(19.2)}{3} = \boxed{84.5^k}$

V_c Lesser of V_{ci} or V_{cw}

Because the shear varies for every i-cut pile and load application, use equation

$V_c = 2\sqrt{f'_c}\, bd$

$b = 24"$

$d = 19.2"$

f'_c (ksi)	V_c (k)
8	82.4
7	77.1
6	71.4

ENG-001/2-84

$$\underline{V_{ci}} = .6\sqrt{f'_c}\, bd + \cancel{V_d}^{\,0} + \frac{V_i M_{cr}}{M_{max}}$$

Let $f'_c = 8000$

$b = 24$

$d = 20.4$

$V_i = R_T = \frac{M}{a} = \frac{778.4^{\text{k-ft}}}{a}$

? — $M_{max} = M = 778.4^{\text{k-ft}} \times 12''/' = 9341^{\text{k-in}}$

$M_{cr} = S\left(6\sqrt{f'_c} + f_{pe} - \cancel{f_d}^{\,0}\right)$

$f_{pe} = 1.145$ ksi

$S = \frac{bh^2}{6} = \frac{24(24)^2}{6} = 2304$

$\therefore M_{cr} = 2304\left(6\sqrt{\frac{8000}{1000}} + 1.145\right) = 3875^{\text{k-in}}$

$\therefore V_{ci} = .6\sqrt{\frac{8000}{1000}} \times 24 \times 20.4 + \frac{\left(778.4/a\right) \cdot 3875}{9341}$

$= 26.3 + 322.9/a$ when a in feet

a	$322.9/a$	V_{ci}
0	∞	∞
5	64.6	90.9
10	32.3	~~58.6~~ →
15	21.5	~~47.8~~ →
20	16.1	~~42.4~~ →
25	12.9	~~39.2~~ →

But $V_{ci} \geq 1.7\sqrt{f'_c}\, bd$

$= 1.7\sqrt{\frac{8000}{1000}} \times 24 \times 20.4$

$= \underline{74.4^{\text{k}}}$ min

Sheet 14 of 34

Project NCEL Phase II

Job No.

Designer CNS

ABAM CONSULTING ENGINEERS

Subject SHEAR CAPACITY

Date 6/8/88

$$\underline{V_{cw}} = \left(3.5\sqrt{f'_c} + .3 f_{pc}\right) bd + \cancel{V_p} \nearrow 0$$

Say $f'_c = 8000$

$f_{pc} = f_{pe} = 1.145$

$b = 24 \quad d = 19.2$

$$\therefore V_{cw} = \left(3.5 \frac{\sqrt{8000}}{1000} + .3 \times 1.145\right) 24 \times 19.2 = \underline{303^k}$$

Conclusion

Concrete shear calculated by $\underline{V_{ci}}$ controls.

$\underline{f'_c = 8000}$ $\quad V_{ci} = 74.4^k$

$V_s = 84.5^k$

$$\therefore \phi V_n = 0.85 (74.4 + 84.5) = \boxed{135^k}$$

Using a factor of safety of 1.5 to go from "ultimate nominal capacity" to "service level capacity" to use with the form fenders:

$$V_{(allow)} = \frac{V_u}{1.5} \leq \frac{\phi V_n}{1.5} = \frac{135}{1.5} = \boxed{90^k}$$

This is the maximum allowable shear on the 24" ▫ pile.

Check strand development

ENG-001/2-84

Strand development

The charts that plot ϕP_n vs. L are all based on developing the nominal moment ϕM_n. This moment is defined as the moment corresponding to:

1) $\varepsilon_c \leq .0021$
2) $f_{ps} \leq 240$ ksi

In order to obtain a strand stress of f_{ps}, the strand must be fully developed. If the strand development length is less than that provided, ratio down the nominal moment; hence, the allowable reaction.

Per ACI Sec. 12.9

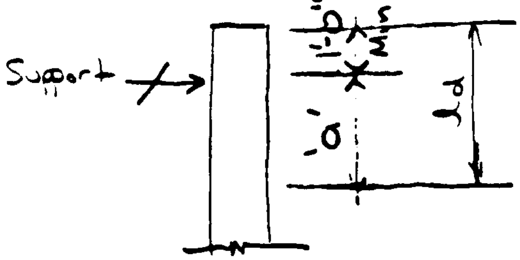
$$l_d = \left(f_{ps} - \tfrac{2}{3} f_{se}\right) d_b$$

$f_{ps} = 240$ ksi max.

$f_{se} = 154$ ksi for stiff pile

$d_b = 1/2"$

$$\therefore l_d = \left(240 - \tfrac{2}{3} \cdot 154\right) \cdot \tfrac{1}{2} = \underline{69"} = \underline{5'-9"}$$



f_{ps} is developed when

$a \geq (5'-9") - (1'-0") = 4'-9"$

Say $a \geq 5'-0"$

Project NCEL Phase II	Sheet 16 of 34
	Job No.
	Designer CWS
Subject Strand Development	Date 6/14/89

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- Determine the allowable 'a' dimension so that the shear strength is not exceeded. Work backwards, knowing the shear capacity.
  - Find ϕV_n w/ $\phi = .85$
  - Find ϕM_n w/ ϕ determined by $\varepsilon_c = .0021$
  - Solve for load location 'a' when both ϕM_n and ϕV_n are both reached simultaneously

f'_c	ϕV_n	ϕM_n @ $\varepsilon_c = .0021$	$a = \phi M_n / \phi V_n$
8	141.9	778.4	5.5
7	137.4	743.5	5.4
6	132.5	708.9	5.4

For 'a' less than this distance, the shear capacity of the pile will control.

Example For $f'_c = 8$ ksi: $\phi M_n = 778.4$ k-ft @ $\varepsilon_c = .0021$

For 24" □ stiff pile, $\phi V_n = .85(166.9^k) = 141.9^k$

The corresponding load application point 'a' is

$$a = \frac{M_n}{R} = \frac{M_n}{V_n} = \frac{778.4^{k\text{-}ft}}{141.9^k} = \underline{5.5'}$$

Project NCEL Phase V — Sheet 17 of 34 — Job No. — Designer CWS — Date 6/8/89

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Subject 24" □ Stiff DESIGN AIDS

Develope Equation for Reaction, R

Baseline Case $f'_c = 8$ ksi $L = 65'$ $a = 15'$ $b = 50'$

$$M = \frac{Pab}{\ell}$$

$M = 778.4$ = constant for all lengths for a given f'_c.

$$\therefore P = \frac{M\ell}{ab}$$

ℓ	a	b	Calculated P	FENDER P	Δ
65	15	50	67.5	67.5	0
40	5	35	177.9	177.9	0
90	20	70	50.0	50.0	0

Good!

Conclusion

Therefore; for a given concrete strength f'_c, the reaction at the point of load is a function of ℓ, a and b. It can be solved by statics.

$$\boxed{P = \frac{M\ell}{ab}}$$ where P: load

ℓ varies 40' to 90' by 5

a varies 0' to 25' by 5

b = $(\ell - a)$

M = controlling moment of cross-section governed by 1) $\varepsilon_c \leq .0021$ in/in
2) $f_{sc} \leq 240$ ksi

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Project NCEL PHASE V

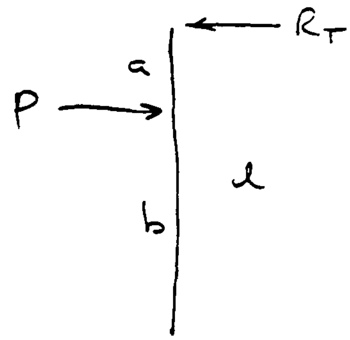
Job No.

Designer CWS

Subject DESIGN AIDS

Date 6/5/88

Reaction @ top of pile



From statics $R_T = \dfrac{Pb}{\ell}$

but $P = \dfrac{M\ell}{ab}$

$\therefore\ R_T = \left(\dfrac{M\cancel{\ell}}{a\cancel{b}}\right) \cdot \dfrac{\cancel{b}}{\cancel{\ell}} = \dfrac{M}{a} = \text{constant}$

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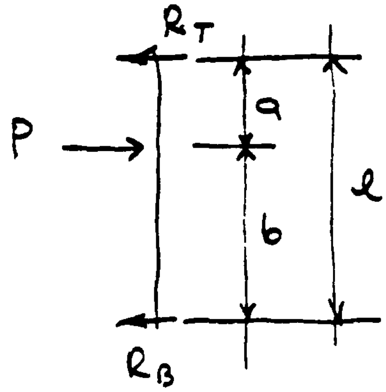
Project NCEL PHASE V

Subject DESIGN AIDS

Job No.

Designer CWS

Date 6/8/88



$$\boxed{P = \frac{Ml}{ab}}$$ – load applied

R_T = reaction @ top of pile
= shear in pile

$$\boxed{\therefore R_T = \frac{Pb}{l} = \frac{M}{a}}$$

Possible lengths, l. 40' to 90' by 5

Possible, a 0 to 25' by 5

write program on HP41·CV to generate the values P and R_T.

1) Set 'M' and 'a' as input constants
2) Select first value of l
3) Compute $b = l - a$
4) Calculate $P = Ml/ab$
5) Increment value of l by 5'
6) Repeat step 3)
7) Calculate $R_T = M/a$

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Sheet 20 of 34

Project NCEL PHASE V

Job No.

Designer CWS

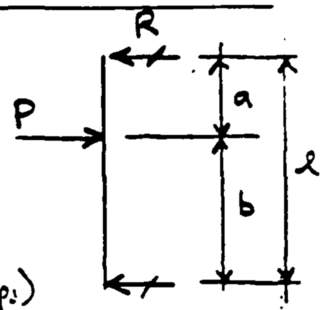
Subject 24" Sq. Pile

Date 6/8/85

Allowable Applied Load, P

$f'_c = \underline{8000 \text{ psi}}$

$\boxed{P = \frac{M\ell}{ab}}$ where $\phi M_n = \underline{778.4}$ k-ft



~~Allowable~~ Applied Load, ϕP_n (kips)

ℓ (ft) \ a (ft)	0	5	10	15	20	25
40	∞	177.9	103.8	83.0	77.8	83.0
45	↑	175.1	100.1	77.8	70.1	70.1
50		173.1	97.3	74.1	64.9	62.3
55		171.2	95.1	71.4	61.2	57.1
60		169.8	93.4	69.2	58.4	53.4
65		168.7	92.0	67.5	56.2	50.6
70		167.7	90.8	66.0	54.5	48.4
75		166.8	89.8	64.9	53.1	46.7
80		166.1	89.0	63.9	51.9	45.2
85		165.4	88.2	63.0	50.9	44.1
90	↓	164.8	87.6	62.3	50.0	43.1
R (k)	∞	155.7	77.8	51.9	38.9	31.1

$R = \frac{Pb}{\ell} = \frac{M}{a}$, R = constant for given 'a'

Sheet 6 of 34

Project NCEL PHASE V

Job No.

Designer CWS

ABAM
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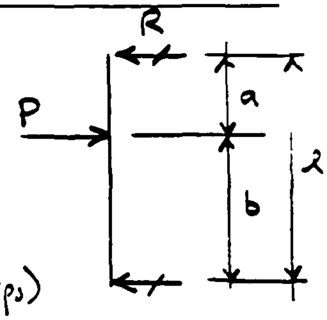
Subject 24" Sq. Pile
Allowable Applied Load, P

Date 6/3/83

$f'_c = \underline{8000\ psi}$

$$\boxed{P = \frac{M\ell}{ab}} \quad \text{where } \phi M_n = \underline{778.4} \text{ k-ft}$$



~~Allowable~~ Applied Load ϕP_n (kips)

ℓ (ft) \ a (ft)	5.5 ~~0~~	6	7	8	9	12
40	164.1	152.6	134.8	121.6	111.6	92.7
45	161.2	149.7	131.7	118.3	108.1	88.5
50	159.0	147.4	129.3	115.8	105.5	85.4
55	157.3	145.6	127.4	113.9	103.4	83.0
60	155.8	144.1	125.9	112.3	101.8	81.1
65	154.6	142.9	124.6	111.0	100.4	79.6
70	153.6	141.9	123.6	109.9	99.2	78.3
75	152.7	141.0	122.6	108.9	98.3	77.2
80	152.0	140.3	121.9	108.1	97.5	76.2
85	151.3	139.6	121.2	107.4	96.7	75.5
90	150.7	139.0	120.6	106.8	96.1	74.8
R (k)	141.5	129.7	111.2	97.3	86.5	64.9

$R = \frac{Pb}{\ell} = \frac{M}{a}$, R = constant for given 'a'

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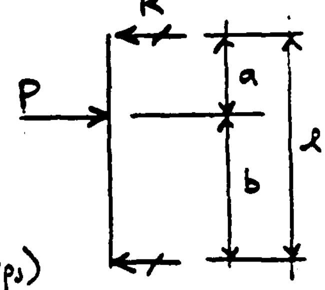
Project: NCEL PHASE V
Subject: 24" Sq. Pile
Allowable Applied Load, P

Sheet: 62 of 34
Job No.:
Designer: CWS
Date: 6/8/88

$f'_c = \underline{7000\ psi}$

$$\boxed{P = \frac{M\ell}{ab}}$$ where $M = \underline{748.5}$ k-ft



Allowable Applied Load, P (kips)

ℓ (ft) \ a (ft)	0	5	10	15	20	25
40	∞	171.1	99.8	79.8	74.9	79.8
45		168.4	96.2	74.9	67.4	67.4
50		166.3	93.6	71.3	62.4	59.9
55		164.7	91.5	68.6	58.8	54.9
60		163.3	89.8	66.5	56.1	51.3
65		162.2	88.5	64.9	54.1	48.7
70		161.2	87.3	63.5	52.4	46.6
75		160.4	86.4	62.4	51.0	44.9
80		159.7	85.5	61.4	49.9	43.5
85		159.1	84.8	60.6	48.9	42.4
90		158.5	84.2	59.9	48.1	41.5
R (k)	∞	149.7	74.9	49.9	37.4	29.9

$R = \frac{Pb}{\ell} = \frac{M}{a}$, R = constant for given 'a'

Project NCEL PHASE V

Job No.

Designer CWS

Date 6/3/88

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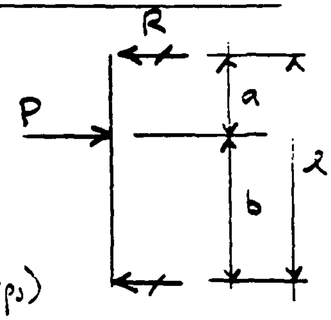
Subject 24" Sq. Pile
Allowable Applied Load, P

$f'_c = 7000$ psi

$$\boxed{P = \frac{M\ell}{ab}}$$ where $M = 748.5$ k-ft



Allowable Applied Load, P (kips)

a (ft) / ℓ (ft)	5.5 ⌀	6	7	8	9	12
40	157.8	146.8	129.6	117.0	107.3	89.1
45	155.0	143.9	126.6	113.8	104.0	85.1
50	152.9	141.8	124.3	111.4	101.4	82.1
55	151.2	140.0	122.5	109.5	99.4	79.8
60	149.8	138.6	121.1	108.0	97.8	78.0
65	148.7	137.4	119.8	106.7	96.5	76.5
70	147.7	136.4	118.8	105.6	95.4	75.3
75	146.9	135.6	117.9	104.7	94.5	74.3
80	146.1	134.9	117.2	104.0	93.7	73.4
85	145.5	134.2	116.5	103.3	93.0	72.6
90	144.9	133.7	115.9	102.7	92.4	72.0
R (k)	136.1	124.8	106.9	93.6	83.2	62.4

$R = \frac{Pb}{\ell} = \frac{M}{a}$, R = constant for given 'a'

Sheet 24 of 34

Project NCEL PHASE V

Job No.

Designer CWS

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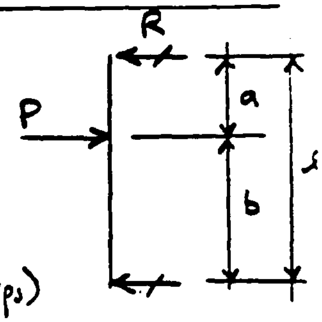
Subject 24" Sq. Pile
Allowable Applied Load, P

Date 6/8/88

$f'_c = \underline{6000 \text{ psi}}$

$$\boxed{P = \frac{M\ell}{ab}} \quad \text{where } M = \underline{708.9} \text{ k-ft}$$



Allowable Applied Load, P (kips)

a (ft) / ℓ (ft)	0	5	10	15	20	25
40	∞	162.0	94.5	75.6	70.9	75.9
45	↑	159.5	91.1	70.9	63.8	63.8
50		157.5	88.6	67.5	59.1	56.7
55		156.0	86.6	65.0	55.7	52.0
60		154.7	85.1	63.0	53.2	48.6
65		153.6	83.8	61.4	51.2	46.1
70		152.7	82.7	60.1	49.6	44.1
75		151.9	81.8	59.1	48.3	42.5
80		151.2	81.0	58.2	47.3	41.2
85		150.6	80.3	57.4	46.4	40.2
90	↓	150.1	79.8	56.7	45.6	39.3
R (k)	∞	141.8	70.9	47.3	35.4	28.4

$R = \frac{Pb}{\ell} = \frac{M}{a}$, R = constant for given 'a'

Project NCEL PHASE V

Job No.

Designer CWS

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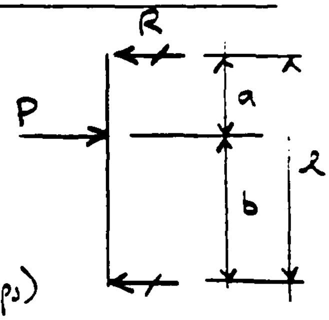
Subject 24" Sq. Pile

Date 6/3/88

Allowable Applied Load, P

$f'_c = \underline{6000 \text{ psi}}$

$$\boxed{P = \frac{M\ell}{ab}}$$ where $M = \underline{708.9}$ k-ft



Allowable Applied Load, P (kips)

ℓ (ft) \ a (ft)	~~θ~~ 5.5	6	7	8	9	12
40	149.4	139.0	122.8	110.8	101.6	84.4
45	146.8	136.3	119.9	107.8	98.5	80.6
50	144.8	134.3	117.8	105.5	96.1	77.7
55	143.2	132.6	116.0	103.7	94.2	75.6
60	141.9	131.3	114.6	102.2	92.7	73.8
65	140.8	130.2	113.5	101.0	91.4	72.5
70	139.9	129.2	112.5	100.0	90.4	71.3
75	139.1	128.4	111.7	99.2	89.5	70.3
80	138.4	127.7	111.0	98.5	88.8	69.5
85	137.8	127.1	110.4	97.8	88.1	68.8
90	137.3	126.6	109.8	97.3	87.5	68.2
R (k)	128.9	118.2	101.3	88.6	78.8	59.1

$$R = \frac{Pb}{\ell} = \frac{M}{a}$$, R = constant for given 'a'

Sheet 26 of 34

Project NCEL PHASE V

Job No.

Designer CWS

Date 6/3/83

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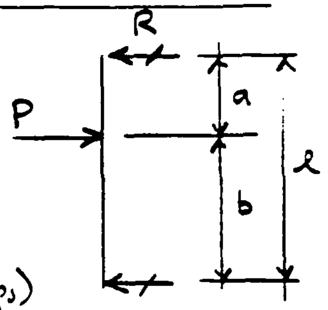
Subject 24" Sq. Pile
Allowable Applied Load, P

$f'_c =$ 000 psi

$$\boxed{P = \frac{M \cdot l}{ab}}$$ where $M =$ ______ k-ft

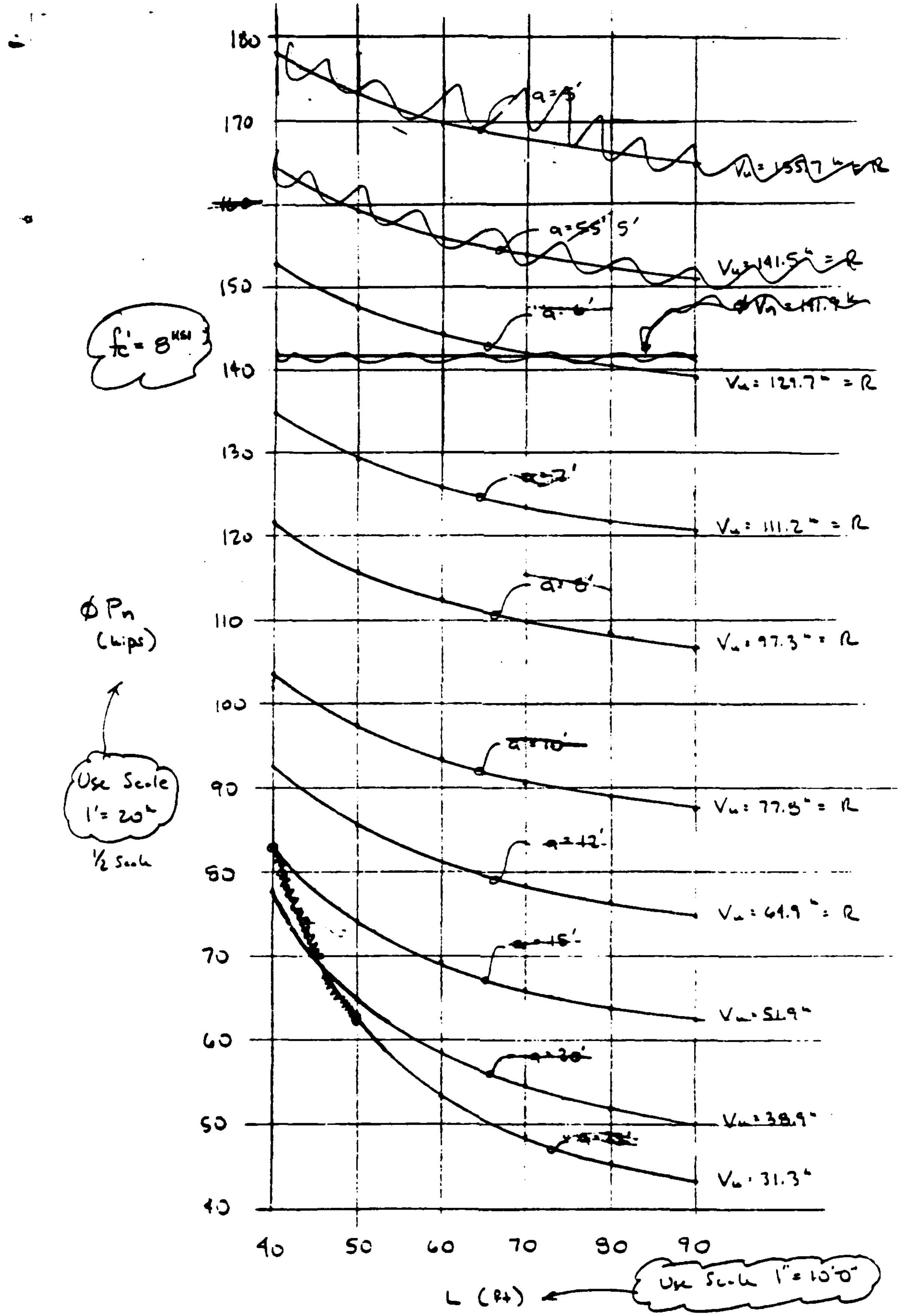


Allowable Applied Load, P (kips)

l (ft) \ a (ft)	0	6	7	8	9	12
40	∞					
45	↑					
50						
55						
60						
65						
70						
75						
80						
85						
90	↓					
R (k)	∞					

$$R = \frac{Pb}{l} = \frac{M}{a}$$, R = constant for given 'a'

ENG-001/2-84



Note: For a < 6', Further investigation must be made considering both shear and strand development

Sheet 23 of 34

Project NCEL Phase II

Job No.

Designer CWS

Subject

Date 8/30/88

ABAM CONSULTING ENGINEERS

Find the "equivalent" ϕ factor

Rather than multipling the nominal strength of the pile at a strain of .003 in/in by $\phi = 0.9$, an equivalent ϕ was used. This ϕ was determined by using the design strength when the pile is at a strain of .003 in/in.

$f'_c = 8$ ksi

$M @ \varepsilon = .003$ in/in $= M_n$

$M_n = 826.8$ k-ft

$M @ \varepsilon = .0021$ in/in $= \phi M_n$

$\phi M_n = 778.4$ k-ft

$\therefore$ Equivalent $\phi = \dfrac{\phi M_n}{M_n} = \dfrac{778.4}{826.8} = .94$

$\boxed{\text{Equiv. } \phi = .94}$

PROJECT: NCEL FENDER SYSTEM STUDY W/ 24" PILES
DATE: 6/8/88
DESIGNER: CWS
PROGRAM: 'FENDER' DEVELOPED BY ABAM ENGR. INC.

DATA FILE: B:24STIFF.DAT
PILE NUMBER: 24" SQ. W/ RECT. STRAND PAT. & f'c = 8
REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

PILE DIMENSIONS:
LENGTH = 65 ft = L
LOAD FROM TOP = 15 ft = a
DEPTH = 24 in
WIDTH = 24 in

CONCRETE DATA:
STRENGTH f'c = 8 ksi
MODULUS E = 4577 ksi
PRESTRESS fpc = 1145 psi

STRAND DATA:
STRAND TYPE = LOW RELAXATION
STRANDS = 28
STRESS fpu = 270 Ksi
STRESS fse = 154 Ksi
MODULUS E = 28000 ksi
AREA = 1.224 sq.in DEPTH = 2.75 in
AREA = .918 sq.in DEPTH = 4.75 in
AREA = 0 sq.in DEPTH = 6.75 in
AREA = 0 sq.in DEPTH = 17.25 in
AREA = .918 sq.in DEPTH = 19.25 in
AREA = 1.224 sq.in DEPTH = 21.25 in

MOMENT Mn (k-ft)	CURVATURE (rad/in)	CONC STRAIN (in/in)	UPPER STRAND STRESS (ksi)	LOWER STRAND STRESS (ksi)	NA DEPTH (in)
234.8	2.085E-05	0.00050	-148.6	-159.4	24.00
374.4	4.[illegible]	0.00070	-144.5	-165.5	17.27
466.3	6.578E-05	0.00090	-140.9	-174.9	13.68
541.3	9.559E-05	0.00110	-137.6	-187.1	11.51
610.3	1.290E-04	0.00130	-134.5	-201.4	10.08
676.5	1.654E-04	0.00150	-131.7	-216.9	9.07
725.5	2.032E-04	0.00170	-129.1	-227.9	8.36
754.8	2.415E-04	0.00190	-126.4	-235.2	7.87
778.4	2.803E-04	0.00210	-123.8	-240.4	7.49
794.2	3.194E-04	0.00230	-121.2	-244.3	7.20
806.2	3.588E-04	0.00250	-118.6	-247.4	6.97
815.7	3.986E-04	0.00270	-116.1	-249.8	6.77
823.4	4.387E-04	0.00290	-113.6	-251.7	6.61
826.8	4.589E-04	0.00300	-112.3	-252.6	6.54

* DATA FILE: B:24STIFF.DAT
* PILE NUMBER: 24" SQ. W/ RECT. STRAND PAT. & f'c = 8
* REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

MOMENT Mn (k-ft)	CONC STRAIN (in/in)	ENERGY (k-ft)	LOAD (kips)	DEFLECTION (in)
234.8	0.00050	0.6	20.3	0.8
374.4	0.00070	2.0	32.5	1.4
466.3	0.00090	3.7	40.4	1.9
541.3	0.00110	6.1	46.9	2.6
610.3	0.00130	9.2	52.9	3.3
676.5	0.00150	13.3	58.6	4.2
725.5	0.00170	17.1	62.9	5.0
756.8	0.00190	20.2	65.6	5.5
778.4	0.00210	22.8	67.5	6.0
794.2	0.00230	25.1	68.8	6.4
806.2	0.00250	27.2	69.9	6.8
815.7	0.00270	29.0	70.7	7.1
823.4	0.00290	30.7	71.4	7.4
826.8	0.00300	31.5	71.7	7.5

PROJECT: NCEL FENDER SYSTEM STUDY W/ 24" PILES
DATE: 6/8/88
DESIGNER: CWS
PROGRAM: 'FENDER' DEVELOPED BY ABAM ENGR. INC.

DATA FILE: B:24STIFF.DAT
PILE NUMBER: 24" SQ. W/ RECT. STRAND PAT. & $\boxed{f'c = 7}$
REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

PILE DIMENSIONS:
LENGTH = 65 ft = L
LOAD FROM TOP = 15 ft = a
DEPTH = 24 in
WIDTH = 24 in

CONCRETE DATA:
STRENGTH f'c = 7 ksi
MODULUS E = 4346 ksi
PRESTRESS fpc = 1145 psi

STRAND DATA:
STRAND TYPE = LOW RELAXATION
STRANDS = 28
STRESS fpu = 270 ksi
STRESS fse = 154 ksi
MODULUS E = 28000 ksi
AREA = 1.224 sq.in DEPTH = 2.75 in
AREA = .918 sq.in DEPTH = 4.75 in
AREA = 0 sq.in DEPTH = 6.75 in
AREA = 0 sq.in DEPTH = 17.25 in
AREA = .918 sq.in DEPTH = 19.25 in
AREA = 1.224 sq.in DEPTH = 21.25 in

MOMENT Mn (k-ft)	CURVATURE (rad/in)	CONC STRAIN (in/in)	UPPER STRAND STRESS (ksi)	LOWER STRAND STRESS (ksi)	NA DEPTH (in)
235.6	2.196E-05	0.00053	-148.3	-159.7	24.00
356.1	3.856E-05	0.00070	-144.7	-164.7	18.16
449.9	6.272E-05	0.00090	-141.0	-173.5	14.35
525.0	9.135E-05	0.00110	-137.6	-184.9	12.04
593.1	1.236E-04	0.00130	-134.5	-198.5	10.52
654.5	1.577E-04	0.00150	-131.5	-213.2	9.51
698.0	1.913E-04	0.00170	-128.5	-224.1	8.89
727.5	2.252E-04	0.00190	-125.5	-231.6	8.44
748.5	2.596E-04	0.00210	-122.6	-237.0	8.09
764.3	2.943E-04	0.00230	-119.6	-241.2	7.81
776.6	3.294E-04	0.00250	-116.7	-244.5	7.59
786.5	3.649E-04	0.00270	-113.9	-247.1	7.40
794.7	4.008E-04	0.00290	-111.0	-249.3	7.24
798.3	4.188E-04	0.00300	-109.6	-250.2	7.16

* DATA FILE: B:24STIFF.DAT
* PILE NUMBER: 24" SQ. W/ RECT. STRAND PAT. & f'c = 7
* REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

MOMENT Mn (k-ft)	CONC STRAIN (in/in)	ENERGY (k-ft)	LOAD (kips)	DEFLECTION (in)
235.6	0.00053	0.7	20.4	0.8
356.1	0.00070	1.8	30.9	1.3
449.9	0.00090	3.4	39.0	1.9
525.0	0.00110	5.6	45.5	2.5
593.1	0.00130	8.6	51.4	3.2
654.5	0.00150	12.2	56.7	4.0
698.0	0.00170	15.4	60.5	4.7
727.5	0.00190	18.1	63.0	5.2
748.5	0.00210	20.4	64.9	5.6
764.3	0.00230	22.5	66.2	6.0
776.6	0.00250	24.4	67.3	6.4
786.5	0.00270	26.2	68.2	6.7
794.7	0.00290	27.8	68.9	7.0
798.3	0.00300	28.6	69.2	7.1

PROJECT: NCEL FENDER SYSTEM STUDY W/ 24" PILES
DATE: 6/8/88
DESIGNER: CWS
PROGRAM: 'FENDER' DEVELOPED BY ABAM ENGR. INC.

DATA FILE: B:24STIFF.DAT
PILE NUMBER: 24" SQ. W/ RECT. STRAND PAT. & f'c = 6
REVISION #: 0
REMARKS: 28 STRANDS W/ 8/6/0 PAT.

PILE DIMENSIONS:
- LENGTH = 65 ft = L
- LOAD FROM TOP = 15 ft = a
- DEPTH = 24 in
- WIDTH = 24 in

CONCRETE DATA:
- STRENGTH f'c = 6 ksi
- MODULUS E = 4098 ksi
- PRESTRESS fpc = 1145 psi

STRAND DATA:
- STRAND TYPE = LOW RELAXATION
- # STRANDS = 28
- STRESS fpu = 270 ksi
- STRESS fse = 154 ksi
- MODULUS E = 28000 ksi

AREA = 1.224 sq.in	DEPTH = 2.75 in
AREA = .918 sq.in	DEPTH = 4.75 in
AREA = 0 sq.in	DEPTH = 6.75 in
AREA = 0 sq.in	DEPTH = 17.25 in
AREA = .918 sq.in	DEPTH = 19.25 in
AREA = 1.224 sq.in	DEPTH = 21.25 in

MOMENT Mn (k-ft)	CURVATURE (rad/in)	CONC STRAIN (in/in)	UPPER STRAND STRESS (ksi)	LOWER STRAND STRESS (ksi)	NA DEPTH (in)
236.5	2.329E-05	0.00056	-148.0	-160.0	24.00
334.4	3.642E-05	0.00070	-145.0	-163.9	19.22
430.8	5.939E-05	0.00090	-141.2	-172.0	15.16
506.3	8.673E-05	0.00110	-137.7	-182.6	12.68
572.7	1.174E-04	0.00130	-134.5	-195.3	11.07
622.3	1.479E-04	0.00150	-131.2	-207.8	10.14
660.1	1.774E-04	0.00170	-127.9	-218.7	9.58
688.1	2.070E-04	0.00190	-124.6	-226.5	9.18
708.9	2.369E-04	0.00210	-121.3	-232.3	8.87
725.0	2.672E-04	0.00230	-118.0	-236.8	8.61
737.8	2.979E-04	0.00250	-114.8	-240.5	8.39
748.4	3.289E-04	0.00270	-111.6	-243.4	8.21
757.4	3.604E-04	0.00290	-108.4	-245.9	8.05
761.3	3.762E-04	0.00300	-106.8	-246.9	7.97

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*	DATA FILE:	B:24STIFF.DAT
*	PILE NUMBER:	24" SQ. W/ RECT. STRAND PAT. & f'c = 6
*	REVISION #:	0
	REMARKS:	28 STRANDS W/ 8/6/0 PAT.

MOMENT Mn (k-ft)	CONC STRAIN (in/in)	ENERGY (k-ft)	LOAD (kips)	DEFLECTION (in)
236.5	0.00056	0.7	20.5	0.8
334.4	0.00070	1.6	29.0	1.2
430.8	0.00090	3.1	37.3	1.8
506.3	0.00110	5.2	43.9	2.4
572.7	0.00130	7.9	49.6	3.1
622.3	0.00150	10.6	53.9	3.7
660.1	0.00170	13.2	57.2	4.3
688.1	0.00190	15.6	59.6	4.8
708.9	0.00210	17.7	61.4	5.2
725.0	0.00230	19.6	62.8	5.6
737.8	0.00250	21.4	63.9	5.9
748.4	0.00270	23.1	64.9	6.2
757.4	0.00290	24.6	65.6	6.5
761.3	0.00300	25.4	66.0	6.7

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